PREPARATION OF LAYERED MATERIAL Zn/Al-LAYERED DOUBLE HYDROXIDE-FERULATE NANOCOMPOSITES

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ABSTRACT

A new layered material-drug nanocomposite namely, Zn/Al-layered double hydroxide-ferulate (Zn/Al-LDH-FA) has been synthesized using the ion exchange method. PXRD pattern and elemental analysis showed that Zn/Al-LDH-FA nanocomposite yielded high crystalline and pure phase material with a basal spacing of 17.4 Å and anion loading of 35.9 % respectively. The FTIR spectra reveal the presence of FA in the interlayer of Zn/Al-LDH, while the thermal analysis shows that the Zn/Al-LDH has enhanced the thermal stability of FA in the interlayer compared to its pure form. Anionic FA intercalated into the interlayer of Zn/Al-LDH as vertical monolayer with the carboxylate groups pointing towards the Zn/Al-LDHs layers. The intercalation of FA into the interlayer of Zn/Al-LDH is also supported by morphology analysis, FESEM.

Keywords: Synthesis, Intercalation, Layered Double Hydroxide, Ferulic Acid

ABSTRAK

Sebuah bahan-obat berlapis nanokomposit baru yaitu, Zn/Al-berlapis ganda hidroksida-ferulate (Zn/Al-LDH-FA) telah disintesis dengan menggunakan metode pertukaran ion. Pola PXRD dan analisis unsur menunjukkan bahwa Zn/Al-LDH-FA nanokomposit menghasilkan kristalinitas tinggi dan material fase murni dengan jarak basal dari 17,4 Å dan pemuatan anion 35,9%. Spektrum FTIR mengungkapkan adanya FA di lapisan Zn/Al-LDH, sedangkan analisis termal menunjukkan bahwa Zn/Al-LDH telah meningkatkan stabilitas termal FA di antar lapisan dibandingkan dengan bentuk murninya. Anionik FA diselingi ke dalam interlayer Zn/Al-LDH sebagai monolayer vertikal dengan gugus karboksilat menunjuk ke arah lapisan Zn/Al-LDHs. Interkalasi dari FA ke dalam interlayer Zn/Al-LDH juga didukung oleh analisis morfologi, FESEM.

Kata kunci: Sintesis, interkalasi, hidroksida berlapis ganda, asam ferulic

INTRODUCTION

Layered material consists of two-dimensional platelets,which are weakly stacked to form three-dimensional structures occupied by water molecules and charged chemical species compatible to those layers (Machovsky, *et al.,* 2013). It is an attractive class of solids which 2D nature commonly gives rise to appeal mechanical, magnetic, thermoelectric, and electronic properties that can be investigated for a richer apprehension of the underlying physics and chemistry of solids. Layered double hydroxide (LDH) is a layered material which belong to the large class of anionic clays (Cavani, Trifiro, & Vaccari, 1991). LDH has a net positive charge and the interlayer which comprises of hydrated anions (He,*et al.,* 2006). The general chemical formula of LDH is $[M_{1-x}^{2+}M_x^{3+}(OH)_2]^{x+}[(A^{m-})_{x/m}.nH_2O]$, where M^{2+} is a divalent metal cation and M^{3+} is a trivalent metal cation; A^{m-} is interlayer anions with charge m; x is the molar ratio of $M^{3+}/(M^{2+}+M^{3+})$ (Hussein, *et al.*,2010). The anionic clay based on hydrotalcite-like compound has interesting properties such as high surface area, basic properties, stable to thermal treatments and memory effect properties as identified in a previous study by Cavani et al.,(1991). Thus LDH has been widely employed as a host or carrier for various types of active agent for instance, drugs (Barkhordari & Yadollahi, 2016; Bi, Zhang, & Dou, 2014; Ribeiro,*et al.*, 2014; Rojas, *et al.,* 2015), herbicides (Ahmad *et al.,* 2014; Hashim,*et al.,* 2014; Hussein,*et al.,* 2010; Muda,*et al.*, 2014; Sarijo, *et al.,* 2013), bactericides (Zhenlan, *et al.,* 2009), food additives (Ghotbi, *et al.*,2009), decontaminating agents (Prasanna, Kamath, & Shivakumara, 2007), polymers (Kovanda, *et al.*, 2010; Yasutake,*et al.*, 2008) and adsorbent (Shan *et al.*, 2014).

Ferulic acid(4-hydroxy-3-methoxycinnamic acid, FA) is a phenolic acid commonly distributed in the plant kingdom which can be found in seeds, leaves, bothin its free form and covalently conjugated to the plant cell wall polysaccharides, glycoproteins, polyamines, lignin and hydroxy fatty acids (Kumar & Pruthi, 2014; Paiva, *et al.,* 2013). It readily forms a resonance stabilized phenoxy radical,due to its phenolic nucleus and an extended side chain conjugation which accounts for many potential applications (Graf, 1992). Over the past few decades, FA is well known to have a wide variety of biological activities such as antioxidants (Graf, 1992), antimicrobial (Ergün, *et al.*, 2011), anti-inflammatory (Ozaki, 1992) , hepatoprotective (Rukkumani, *et al.,* 2004), antiallergic (Kumar & Pruthi, 2014), anticarcinogenic (Srinivasan, Sudheer, & Menon, 2007), increase sperm viability (Zheng & Zhang, 1997), antithrombotic (Hong,*et al.,* 2016), antiviral and vasodilatory actions (Huang,*et al.,* 2013), signal transduction (Srinivasan,*et al.,* 2007) and metal chelation (Andjelkovic *et al.,* 2006). Therefore, this study aim at the development of Zn/Al-LDH as a host for anionic ferulic acid via ion exchange method to form a new layered material Zn/Al-layered double hydroxide-ferulate nanocomposite.The ion exchange method is well known due to its ease of substitution of initial and incoming anions within the interlayer region and able toacquaint with a bigger size of anion (He, 2015; Hussein,*et al.,* 2010).

MATERIAL AND METHOD

Preparation of Zn/Al-LDH-FA nanocomposites

All solutions were prepared using deionized water, and the chemicals used without any further purification. The Zn/Al-LDH was prepared using the self assembly method. The initial molar ratios of zinc to aluminium in the mother liquor were fixed at 3. A mixed aqueous solution of zinc nitrate and aluminium nitrate was prepared at pH=7.50 ± 0.05 by dropping wise addition of 2 M aqueous NaOH solution with vigorous stirring.The precipitate was aged at 70 ºC for 18 hours, centrifuged and washed several times with deionize water, then dried in an oven at 70 ºC. The dried sample was ground into fine powder and kept in a sample bottle for further use in preparation ofZn/Al-LDH-FA nanocomposite by the ion exchange method.

Ferulic acid solution was prepared in 50 mL volumetric flask and 0.2 g of Zn/Al-LDH was suspended in 20 ml of distilled water. Ferulic acid solutions were added to the Zn/Al-LDH suspension and magnetically stirred for 2 ½ hours at room temperature. The solutions were aged at 70°C for 24 hours in an oil bath shaker. The precipitates were centrifuged, thoroughly washed with deionized water and dried in an oven at 60 °C overnight. The resulting materials were ground and stored in a sample bottle for characterization.

Characterization

The samples are characterized by Powder Diffraction Bruker AXS (model D8 Advance, wavelength of 0.15406 nm). The CuK_{α}irradiation was applied at an operating potential at 60 kV and a current of 60 mA with a scanning rate of 0.025 $°s^{-1}$.FTIR spectra were recorded using a Thermo Nicolet 6700 Fourier transform infrared spectrometer in the range 400–4000 cm^{-1}. Thermal gravimetric analyses and differential thermal gravimetry (TGA-DTG) of a sample were recorded using Perkin Elmer Pyris 1 TGA Thermo Balance with a heating rate of 20 °C min-1. Field Emission Scanning Electron Microscope (FESEM) (Hitachi model SU 8020 UHR) was employed to studythe morphology of a sample. The composition of the samples was measured by inductive coupled plasma optical emission spectrometry (ICP-OES), model Agilent, 720 Axial and elemental analyzer (CHNO-S), model Thermofinnigan, FlashEA 1112 Series heated with a constant flow of helium stream and enriched with oxygen of 99.9995% purity.

RESULTS AND DISCUSSION

PXRD analysis

Figure 1 shows the XRD patterns of FA,Zn/Al-LDHand Zn/Al-LDH-FA nanocomposites prepared using various concentrations of FA which are 0.025 M, 0.030 M and 0.050 M using ion-exchange method. XRD patterns ofZn/Al-LDH showed three reflections were found (003, 006 and 009) at a lower angle 2θ with basal spacing8.8 Å that indicated the presence of nitrates as compensating ions in agreement with previous reports [Bashi, *et al.*, 2012; Barahuie, *et al.*, 2014].

As shown in Figure 1, concentrations of FA did not affect the values of basal spacing of the nanocomposites. XRD patterns show that all nanocomposites with

concentrations 0.025 M, 0.030 M and 0.05 M had same d-spacing valueof 17.4 Å. The expansion of d-spacing from Zn/Al-LDH to Zn/Al-LDH-FA nanocomposites indicated that the FA anions were successfully intercalated into the interlayer gallery of Zn/Al-LDH to form a new layered material nanocomposite namely,Zn/Al-LDH-FA nanocomposite. Compared to nitrate anions, ferulate anions have bigger size and higher density resulted in the expansion of d-spacing. As shown in the figure, nanocomposite with concentration of 0.025 M FA showed pure phase with sharp and intense peak due to its highestcrystallinitycompared to other concentrations therefore, this nanocomposite was chosen to be used in further characterization.

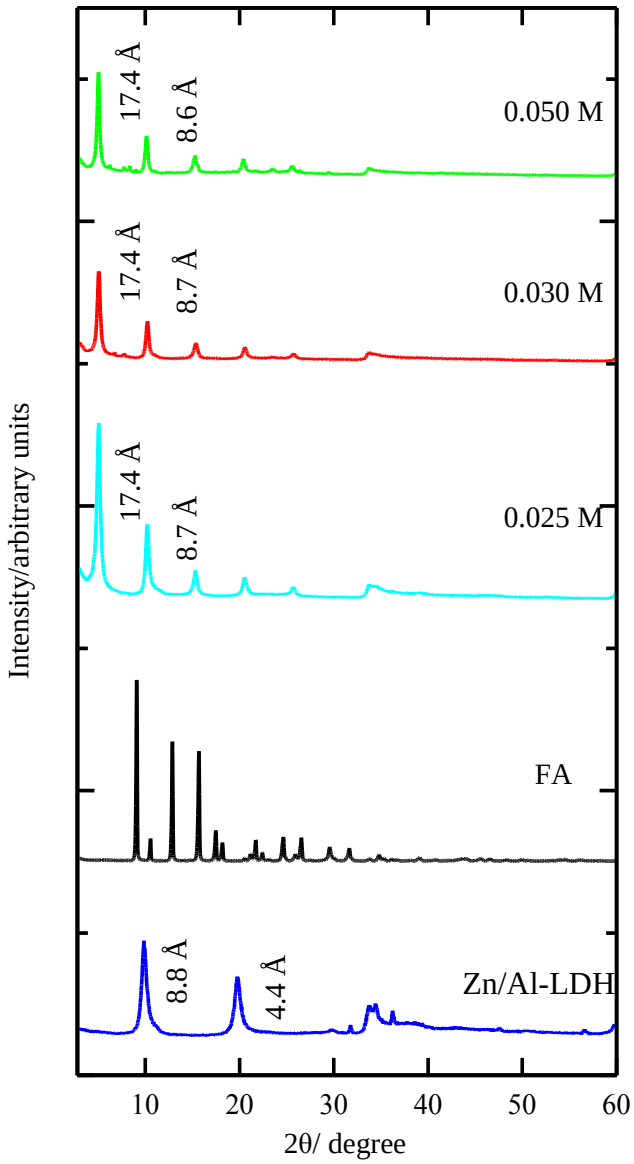

Fig. 1. Powder X-ray diffraction patterns of Zn/Al-LDH, FA, and Zn/Al-LDH-FA nanocomposites prepared using 0.025 M, 0.030 M and 0.050 M of FA

Spatial orientation of Zn/Al-LDH-FA nanocomposite

Figure 2 shows the 3D molecular size of FA calculated by Chem3d Ultra 8.0 software. The long and short axes and molecular thickness of FA was 12.6 Å, 8.9 Å and 4.2 Å, respectively.The XRD pattern observed from Figure 1 showed that the d-spacing of theZn/Al-LDH-

FA nanocomposite increased to 17.4 Å. As the thickness of the Zn/Al-LDH layer is 4.8 Å [Cavani,*et al.*, 1991], the gallery height of Zn/Al-LDH after intercalation is estimated to be about 12.6 Å, obtained by subtracting the thickness ofZn/Al-LDH (17.4 Å–4.8 Å), which is identical to the longest axis of FA. Based on this result, the orientation of ferulate molecules in the interlayer of Zn/Al-LDH was proposed in the arrangement of vertical monolayer with the carboxylate groups oriented towards the brucite-type layers in order to enhance the electrostatic interactions (Figure 3).

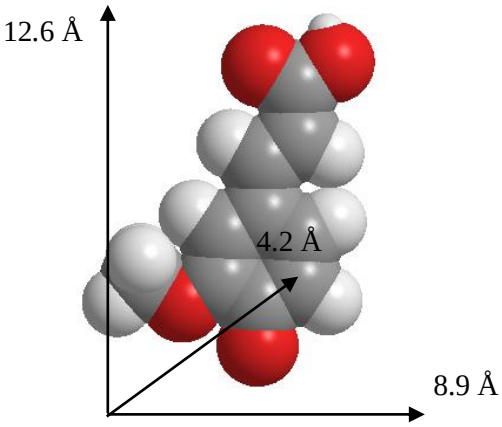

Fig.2. 3D molecular structure of FA

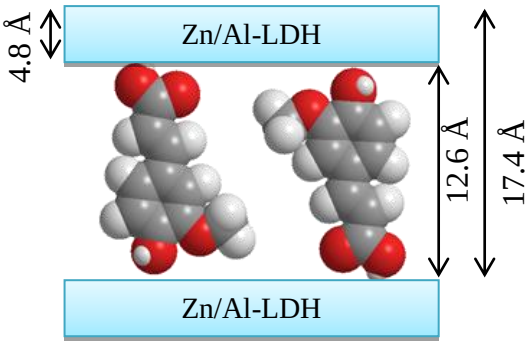

Fig. 3. Proposed spatial orientation of FA in the Zn/Al-LDH inorganic interlayer

FTIR spectroscopy

The FTIR spectra of Zn/Al-LDH, pure FA and Zn/Al-LDH-FA nanocomposites in the region between 400–4000 cm^{-1} are illustrated in Figure 4. The FTIR spectrum of Zn/Al-LDH shows a broad absorption band in the range of 3200–3600 cm-^{1} centered at 3450 cm^{-1} which attributed to the O–H group in the layer [Barahuie,*etal.*, 2014; Kura,*et al.*, 2014]. A sharp and intense peak was at 1385 cm^{-1} and a less intense absorption band at 1633 cm^{-1} were observed are attributed to the symmetric stretching of the NO_3^- group. Two weak bands were found at around 600 cm^{-1} and 430 cm^{-1} can be assigned to the metal oxygen and metal hydroxide stretching modes [Barahuie,*et al.*, 2014].

Figure 4shows the FTIR spectrum of pure FA with strong characteristic vibration at 3430 cm^{-1} which indicated to the O–H stretching. A characteristic band of FA at 1692 cm^{-1} corresponds to stretching vibration of an undissociated carboxylic group (COOH), while those at 1595 cm^{-1} and 1428 cm^{-1} refer to the aromatic nucleus of FA [Kim,*et al.*, 2013]. The bands at 1269 cm^{-1} and 1234 cm^{-1} were due to ν_{as} (COC) and ν_s (COC).

The FTIR spectrum of Zn/Al-LDH-FA nanocomposite in Figure 4 illustrates the combined spectra features of both functional groups of FA and Zn/Al-LDH which supported the successful intercalation of FA in the interlayer gallery of Zn/Al-LDH. Some of the bands were slightly shifted in position due to the interaction betweenZn/Al-LDH layers and the organic guest, FA anions. The most notable feature after the intercalation of FA into the interlayer of Zn/Al-LDH is

the disappearance of C=O in the carboxylic group at 1692 cm^{-1}, as well as the formation of the new two peaks at 1522 cm^{-1} and 1400 cm^{-1} which can be assigned for asymmetric and symmetric stretching of carboxylate group. Additionally, absorption bands attributed to NO_3^- stretching at 1385 cm^{-1} and 1633 cm^{-1} have disappeared indicate that the nitrate anions were completely exchanged with FA anions to form Zn/Al-LDH-FA nanocomposite (Hussein, Rahman, Sarijo, & Zainal, 2012). A broad band at 3438 cm^{-1} can be attributed to OH stretching vibrations. The vibration bands of FA andZn/Al-LDH-FA nanocomposite are listed in Table 1.

Table 1 Fourier transform infrared vibration bands for FA and Zn/Al-LDH-FA nanocomposite

Functional groups	FA	Zn/Al-LDH-FA nanocomposite
V (O–H)	3430	3438 in the
v (C=O) in	for	layer, H_2O
COOH	O–H in	-
v_{as} (COO^-)	COOH	1522
	1692	1400
v (C=C);	-	1597
aromatic	-	1467
ring	159	1274
	1428	1218
vas	1269	853
(C–O–C)	1234	821
	853	
C–H out of	806	
plane	752	
bending	689	

Elemental analysis

Elemental analyses of Zn/Al-LDH and Zn/Al-LDH-FA nanocomposite are shown in Table 2. The final molar ratio of Zn to Al in Zn/Al-LDH was 2.8 compared to 3.0 for the value initially prepared for mother liquor, meanwhile in Zn/Al-LDH-FA nanocomposite the molar ratio of Zn to Al was 1.61. The lower molar ratio of Zn to Al in Zn/Al-LDH-FA nanocomposite was due to less Al^{3+} ions present in thenanocomposite. CHNS analysis shows that Zn/Al-LDH-FA nanocomposite contains 22.20 % carbon (w/w) and the loading percentage of FA in the Zn/Al-LDH-FA nanocomposite is 35.90 % (w/w). These results showed that FA anion was successfully intercalated between the interlayer of Zn/Al-LDH. From the elemental analysis and thermogravimetric studies, the formula for Zn/Al-LDH and Zn/Al-LDH-FA nanocomposite could beproposed as $[Zn_{0.74}Al_{0.26}(OH)_2](NO_3^-)_{0.26}.043H_2O$ and $[Zn_{0.62}Al_{0.38}(OH)_2][OHCH_3OC_6H_3CHCHCOO^-]_{0.38}.2.45H_2O$, respectively.

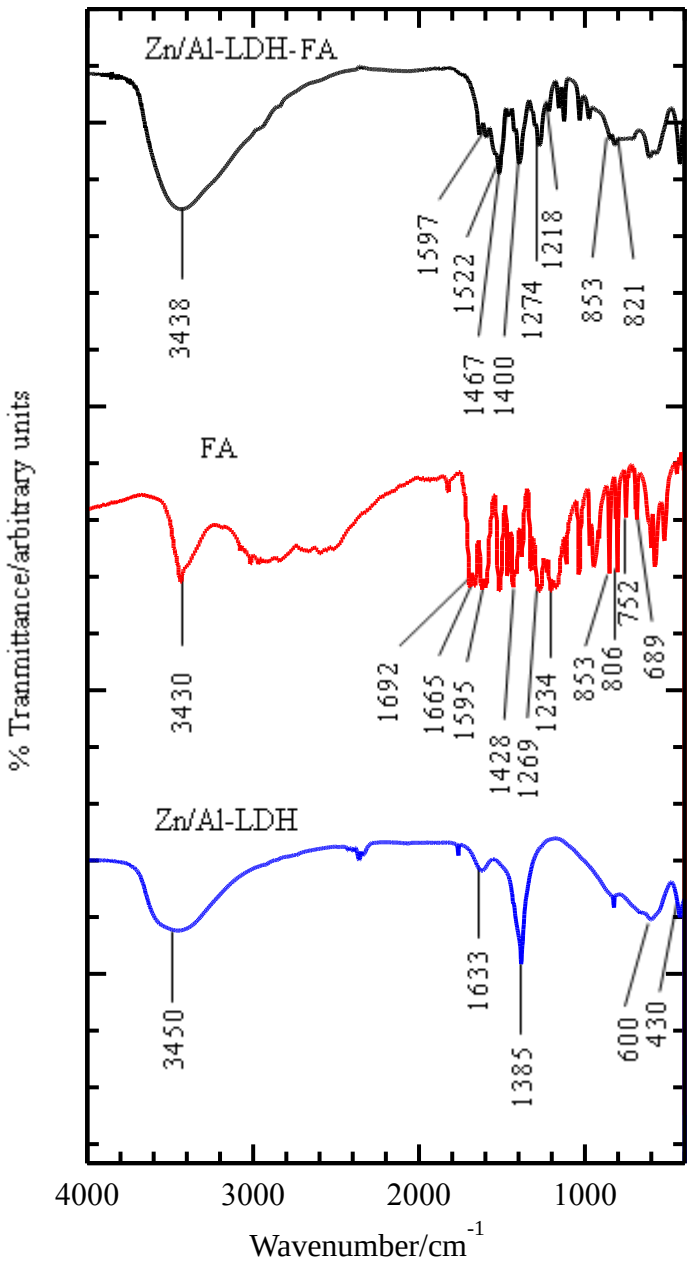

Fig. 4. FTIR spectra of LDH, FA and Zn/Al-LDH-FA nanocomposite

Thermal Studies

In this section, the thermal decomposition behavior of the Zn/Al-LDH-FA nanocomposite has been studied. The TGA/DTG analysis of FA, Zn/Al-LDH andZn/Al-LDH-FA nanocomposite are shown in Figure 5. As shown in Figure 5(a), the TGA/DTG thermograms of pure FA showed a single sharp weight loss of 100 % at a maximum temperature of 255 °C, attributed to complete combustion of FA.

Table 2 Compositional data for synthesized Zn/Al-LDH and Zn/Al-LDH-FA nanocomposite materials at different ratio

Sample	Zn/Al Ratio	C (%)	N (%)	Mole Fraction		[a]FA (%w/w)	Formula
				X_{Zn}	X_{Al}		
Zn/Al-LDH	2.8	-	3.0	0.74	0.26	-	$[Zn_{0.74}Al_{0.26}(OH)_2](NO_3^-)_{0.26}.0.43H_2O$
Zn/Al-LDH-FA	1.6	22.20	-	0.62	0.38	35.90	$[Zn_{0.62}Al_{0.38}(OH)_2][OHCH_3OC_6H_3CHCHCOO^-]_{0.38}.2.45H_2O$

[a]= estimated from CHNS-O analysis

The thermal decomposition of Zn/Al-LDH (Figure 5(b)) shows four thermal events of weight losses which occurred at 139, 286, 346 and 484 °C with weight loss of 7.3 %, 15.4 %, 7.5 % and 5.7 %, respectively. The first stage of weight loss could be associated with the removal of water physisorbed on the external surface of Zn/Al-LDH. The second stage weight loss corresponded to strongly held water molecules (Fernandez, *et al.*, 1998)]. The third and fourth stages of weight loss were due to dihydroxylation of the Zn/Al-LDH together with the decomposition of nitrate anions.

After the intercalation process, the thermal behavior of the resulting nanocomposite was significantly different from that of the precursor. The thermal decomposition of Zn/Al-LDH-FA nanocomposite (Figure 5 (c)) exhibited more complicated with four stages of weight loss at maximum temperatures of 67, 199, 323 and 663 °C with percentage of weight loss of 12.7 %, 9.1 %, 12.7 %, and 22.1 % respectively. The first stage of weight loss 12.7 % was ascribed to the removal of surface adsorbed water. The second stage with weight loss of 9.1 % was attributed to the intercalated water molecule in theZn/Al-LDH-FA nanocomposite [Ghotbi & Hussein, 2010]. The third stage weight loss of 12.7 % was due to dihydroxylation of the hydroxide layers which can be seen at 250–380 °C. The fourth stage with a weight loss of 22.1
% at 663 °C corresponded to the thermal decomposition of organic species, ferulate anions and the removal of the last carbonaceous residues formed by the decomposition of the organic anions [Bashi,*et al.*, 2012]. The thermal decomposition of ferulate in Zn/Al-LDH-FA were observed in the 380–800 °C region, compared to free ferulic acid in 200–350 °C, suggesting that inorganic layers of Zn/Al-LDH enhanced the thermal stability of FA.

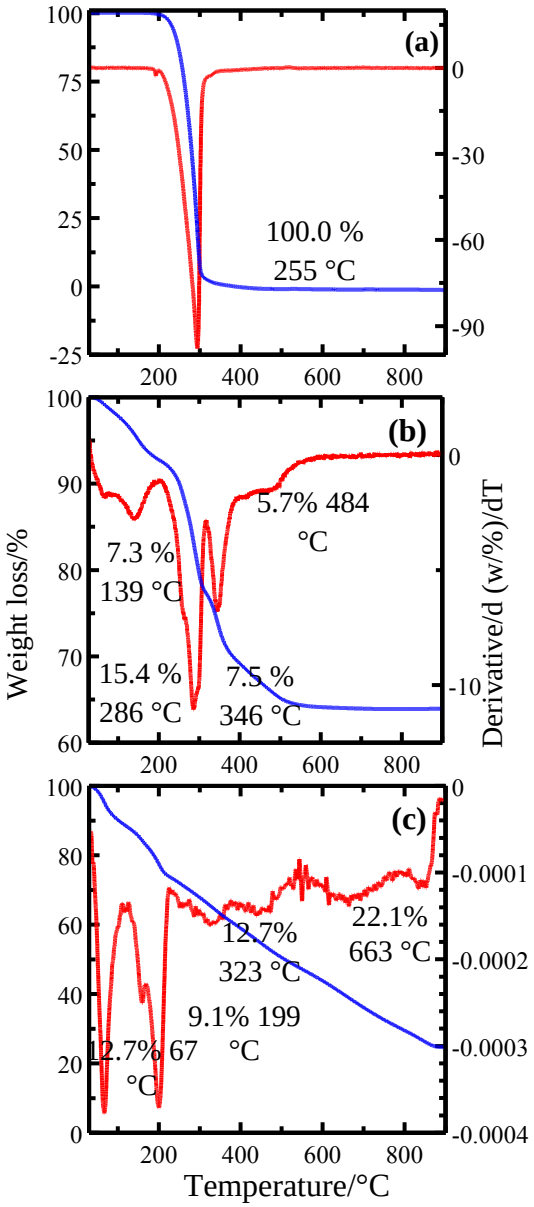

Fig.5. TGA/DTG thermograms of (a) FA, (b) Zn/Al-LDH, (c) Zn/Al-LDH-FA nanocomposite.

Surface morphology analysis

The surface morphologies of Zn/Al-LDH andZn/Al-LDH-FA nanocomposite are illustrated in Figure 6. Both Zn/Al-LDH and Zn/Al-LDH-FA nanocomposite showed typical non-uniform irregular agglomerates of compact and non-porous plate-like structures, in agreement with the morphology of nanocomposites discussed in the literature (Raki, *et al.*, 2004). As shown in Figure 6,Zn/Al-LDH-FA nanocomposite showed a smoother surface morphology with smaller plate-like structure compared to Zn/Al-LDH which may be due to the intercalation of FA into the interlayer of Zn/Al-LDH.

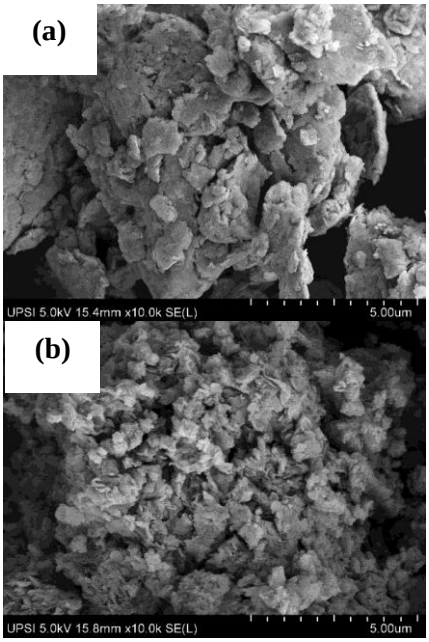

Fig.6. FESEM images of (a) Zn/Al-LDH, (b) Zn/Al-LDH-FA nanocomposite

CONCLUSIONS

Anionic FA was successfully intercalated into the interlayers of Zn/Al-LDH via ion exchange method to form a new layered material-drug nanocomposite namely Zn/Al-LDH-FA nanocomposite. The basal spacing of Zn/Al-LDH was expanded to maximize the drug–host interactions in the intercalation compound, Zn/Al-LDH-FA in which the intercalated FA anions were attracted to positivelycharge of interlayer galleries.The FTIR spectra of the nanocomposite showed the resemblance of FAanion which confirms the intercalation was successful with a loading percentage of

35.9 % (w/w). The Zn/Al-LDH-FA nanocomposite also turns out to have higher thermal stability than FA anion. Based on this study, Zn/Al-LDH is capable to be aexcellent carrier for FA and has a great potential in controlled release formulation of the drug, FA.

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