

# Ultrasound-assisted one-pot preparation of organo-modified nano-sized layered double hydroxide and its nanocomposites with polyvinylpyrrolidone

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Received: 12 August 2013 / Accepted: 26 December 2013  
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**Abstract** In this contribution, polyvinylpyrrolidone (PVP) nanocomposites (NCs) with novel chiral diacid intercalated layered double hydroxides (LDHs) as nanofillers were prepared via ultrasonic irradiation. Chiral LDH was synthesized in one step via a co-precipitation reaction in aqueous solution under ultrasonic irradiation. The modified Mg-Al LDH shows an increase in interlayer distance as compared to the unmodified Mg-Al LDH by X-ray diffraction (XRD). Different NCs of organo-modified chiral LDHs and PVP were constructed by means of an ultrasonic process. The structures of these new materials were investigated by XRD, Fourier transform infrared, field emission scanning electron microscopy and transmission electron microscopy techniques. XRD and electron microscopy results confirmed the delaminated state of the LDH in the PVP matrix. Furthermore, thermal analysis was evaluated and the prepared NCs show significantly improved thermal stability at higher temperature because of the homogeneous and good dispersion of modified LDH in polymeric matrix.

**Keywords** Nanocomposites · Chiral layered double hydroxides · Polyvinylpyrrolidone · Ultrasonic irradiation · X-ray diffraction

## Introduction

With the ever-increasing concern of the environmental risks, non-toxic chemicals are receiving much more attention in recent years [1]. Therefore, water soluble polymers such as polyvinylpyrrolidone (PVP), poly(vinyl alcohol) and poly(ethylene oxide) have been widely investigated in recent decades. PVP with chemical composition of  $C_6H_9NO$ , is a nonionic polymer with amphiphilic character and contains a carbonic backbone to which pyrrolidine rings are attached [2, 3]. It is commercially available as a hygroscopic white solid of  $1.2 \text{ g/cm}^3$  density and of molar mass from 10,000 to 1,200,000, which corresponds to the chain lengths of 90 to 11,000 segments. This polymer is non-toxic, biocompatible, and amorphous with glass transition point ranging from 110 to 180 °C depending on the molar mass [4, 5].

PVP is a water-soluble synthetic polymer with a number of interesting features and unique properties which have lead to a diversity of applications and make it very interesting scientifically [6]. Specifically, PVP, which can be used as a pigment dispersant, bonding agent, suspension stabilizer, and has been studied for fabrication of its nanocomposites (NCs) [6–9]. In order to improve the performance of the composites, the interfacial interaction between the polymer matrix and the inorganic fillers has to be considered. PVP is also of interest to geochemists, soil scientists and clay mineralogists due to its specific interactions with clay minerals. It stabilizes colloidal clay particles; as an adsorbent it is intercalated into clay mineral particles or leads to their exfoliation allowing one to quantify smectite, to measure the thickness distribution of

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fundamental particles and to quantify the total specific surface area and content of smectite [10–14].

Layered double hydroxides (LDHs), or hydrotalcite-like clays, have attracted considerable attention due to their technological importance in different area [15, 16]. LDHs are a class of ionic lamellar compounds fabricated of positively charged brucite-like layers with an interlayer region containing charge compensating anions and solvation molecules. The metal cations occupy the centers of edge sharing octahedral, whose vertexes contain hydroxide ions that connect to form infinite 2D sheets. The most usually studied LDHs contain both divalent and trivalent metal cations; a generic formula for these LDHs may be written as  $[M^{2+}_{1-x}M^{3+}_x(OH)_2](A^{n-})_{x/n} \cdot nH_2O$  where  $M^{2+}$  may be common;  $Mg^{2+}$ ,  $Zn^{2+}$ , or  $Ni^{2+}$  and  $M^{3+}$  may be common;  $Al^{3+}$ ,  $Ga^{3+}$ ,  $Fe^{3+}$ , or  $Mn^{3+}$ .  $A^-$  is a nonframework, charge-compensating inorganic or organic anion, e.g.  $CO_3^{2-}$ ,  $Cl^-$ ,  $SO_4^{2-}$ ,  $RCO_2^-$ , and  $x$  is normally between 0.2 and 0.4 [17–21]. LDHs may also contain  $M^+$  and  $M^{4+}$  cations but these are limited to specific examples such as  $Li^+$  and  $Ti^{4+}$  [21]. The lamellar structure and anion exchange properties of LDHs make them attractive for technological application such as precursors for preparing  $CO_2$  adsorbents, catalysts, or directly as ion exchange hosts, fire retardant additives, drug delivery hosts, and as cement additives [22–29]. Particular attention is now paid to LDHs, which are largely illustrated by polymer-clay nanocomposites that employ cationic mineral clays such as smectites [30–32].

Delamination of LDHs is an interesting route for producing positively charged thin platelets with a thickness of a few atomic layers, which can be used as NCs for polymers, or as building units for making newly designed nanomaterials [33, 34]. Compared to cationic clays such as montmorillonite and laponite, which may be exfoliated into single clay sheets in aqueous suspension, LDHs are more difficult to be delaminated. The high charge density of the LDH layers and the high anion content result in strong interlayer electrostatic interactions between the sheets and a significant hydrophilic character. Often extensive interlamellar hydrogen bonding networks lead to a tight stacking of the lamellae. The rigid spheroidal “sand rose” morphology of intergrown platelets prevents both accessibility to the major part of the surface or exfoliation of the sheets in water or in any other nonaqueous solvents [21, 33–36]. Therefore, in order to delaminate successfully LDHs into nanosheets, new procedures need to be developed. One method for delamination of LDHs into a polymer matrix is surface modification [21, 22].

The present work deals with preparation and characterization of chiral diacid modified LDH and the effect of this nanofiller on the thermal and microstructure properties of PVP NCs. Different amounts of this novel modified LDH were used for the synthesis of PVP/modified LDH NCs under simple ultrasonic process by solution casting method. The novel synthesized materials were subjected to X-ray

diffraction (XRD), Fourier transfer infrared (FT-IR) and thermogravimetric analysis (TGA) techniques. The morphology of obtained materials was examined by field emission scanning electron microscopy (FE-SEM) and transmission electron microscopy (TEM) techniques.

## Experimental

### Materials

All chemicals used were purchased from Fluka Chemical Co. (Buchs, Switzerland), Aldrich Chemical Co. (Milwaukee, WI, USA), Riedel-deHaen AG (Seelze, Germany) and Merck Chemical Co (Darmstadt, Germany). The PVP (MW=40,000), magnesium nitrate  $Mg(NO_3)_2 \cdot 6H_2O$ , aluminum nitrate  $Al(NO_3)_3 \cdot 9H_2O$ , sodium hydroxide (NaOH), trimellitic anhydride (TMA,  $C_9H_4O_5$ ,  $M_w$ : 192.01 g/mol) and L-valine were used without further purification. The other materials and solvents were used as obtained without further purification.

### Characterizations

The reaction was carried out on MISONIX ultrasonic liquid processors, XL-2000 SERIES (Raleigh, NC, USA). The ultrasound used a wave of frequency  $2.25 \times 10^4$  Hz and power of 100 W.

FT-IR spectra were recorded on Jasco-680 (Tokyo, Japan) spectrophotometer with  $2\text{ cm}^{-1}$  resolution. The KBr pellet technique was applied for monitoring changes in the FT-IR spectra of the samples in the range of  $4,000\text{--}400\text{ cm}^{-1}$ . The vibrational transition frequencies are reported in wavenumbers ( $\text{cm}^{-1}$ ).

The interlayer spacing of the organoclays was measured by XRD (Bruker, D8 Advance, Germany) with  $Cu\ K\alpha$  radiation ( $\lambda=0.1542\text{ nm}$ ) at 45 kV and 100 mA. The diffraction patterns were collected between  $2\theta$  of  $1.2^\circ$  and  $70^\circ$  at a scanning rate of  $0.05^\circ/\text{min}$ . Basal spacing was determined from the position of the  $d(001)$  reflection. The scanning speed was  $0.02^\circ/\text{s}$ . The  $d$ -spacing of the organic LDH was analyzed by using Bragg's equation ( $n\lambda=2d\sin\theta$ ), where  $n$  is an integer,  $\lambda$  is the wavelength,  $\theta$  is the glancing angle of incidence, and  $d$  is the interplanar spacing of the crystal.

TGA was performed on a STA503 TA instrument (Hullhorst, Germany) in a nitrogen atmosphere by heating rate of  $10\text{ }^\circ\text{C}/\text{min}$  from ambient temperature to  $800\text{ }^\circ\text{C}$  at nitrogen atmosphere.

The morphology of the nanostructure materials was examined by FE-SEM [HITACHI; S-4160, (Tokyo, Japan)]. The powdered sample was dispersed in  $H_2O$ , and then the sediment was dried at room temperature before gold coating.

The nanostructure morphology of the novel materials was also examined by TEM. The TEM images were obtained

using a Philips CM120 (Eindhoven, the Netherlands) using an accelerator voltage of 100 kV. The inorganic components appear black/grey colored on the micrographs.

#### *Synthesis of LDH-CO<sub>3</sub><sup>2-</sup> via ultrasonication*

The Mg<sub>2</sub>Al-LDH was simply prepared using an ultrasonic method. Aqueous solutions containing Mg(NO<sub>3</sub>)<sub>2</sub> · 6H<sub>2</sub>O and Al(NO<sub>3</sub>)<sub>3</sub> · 9H<sub>2</sub>O with 2:1 molar ratio was slowly added into the solution containing NaOH (0.08 g) and Na<sub>2</sub>CO<sub>3</sub> (0.16 g) and the pH of the resulting suspension was maintained at 8–9 by continuous addition of a 1 M NaOH for 1 h. The mixed solution was ultrasonicated for 1 h. Finally, the obtained precipitates were filtered using Whatman filter paper and washed with deionized water several times; then the remaining powder was dried at 60 °C for 24 h to obtain CO<sub>3</sub><sup>2-</sup>/Mg-Al LDH.

#### *Sonochemical synthesis of diacid intercalated MgAl-LDH (LDH-diacid)*

Chiral diacid of *N*-trimellitylimido-*L*-valine (diacid) was prepared according to previous works [37, 38]. Intercalation of this diacid in the MgAl-LDH was carried out in one step under ultrasonic irradiation. Al(NO<sub>3</sub>)<sub>3</sub> · 9H<sub>2</sub>O, Mg(NO<sub>3</sub>)<sub>2</sub> · 6H<sub>2</sub>O (Mg/Al molar ratio of 2:1) were dissolved in deionized water (200 mL) to obtain solution, and an aqueous solution containing NaOH (0.02 mol) and diacid (0.02 mol) was prepared and stirred at room temperature. The solution was adjusted to pH=9.0 by the addition of 1 mol/L NaOH solution. The resultant suspension was sonicated for 1 h. Finally, the obtained precipitate (LDH-diacid) was filtered and washed with deionized water and then dried at 60 °C for 24 h.

#### *Synthesis of PVP/LDH-diacid NCs*

NCs of PVP and LDH-diacid were synthesized by a solution-intercalation method using ultrasound energy: At first, deionized water was mixed with LDH-diacid to form clay/water suspension of ≤2.5 % concentration. The suspension was stirred for 3 h at 40 °C and sonicated for 1 h. PVP was then added to the stirred suspensions to make the total solid (silicate plus polymer) concentration  $w = 5$  %. The mixture was then heated to 90 °C for 2 h to dissolve PVP. The mixed solution was condensed and the total solid concentration controlled at  $w = 10$  %. After being sonicated for 1 h, the final films were made via casting on a Petri dish in a closed oven at 40 °C for 24 h.

## Results and discussion

### Preparation of modified chiral LDH and PVP/LDH-diacid NCs

Ultrasound is now extensively used in different areas of nanochemistry and related fields of nanotechnology. Its main advantages, in comparison to conventional mixing, are faster processes, higher yields, and the possibility of fabricating novel compounds, substances or materials which are impossible or difficult to obtain via classic interactions. In this study, a simple, fast and green procedure was proposed for the synthesis of MgAl-LDH and chiral modified LDH under ultrasound irradiation via a one-step co-precipitation reaction. Bioactive *N*-trimellitylimido-*L*-valine diacid was synthesized according to our previous study as shown in Scheme 1. This compound was then used for preparation of chiral modified LDH. The spatial orientation of the LDH-diacid is shown in Fig. 1. It only serves to emphasize the process of adsorption and does not provide information on the order in which the adsorbent molecules are present along with carboxylate ions ionically bound on the surface.

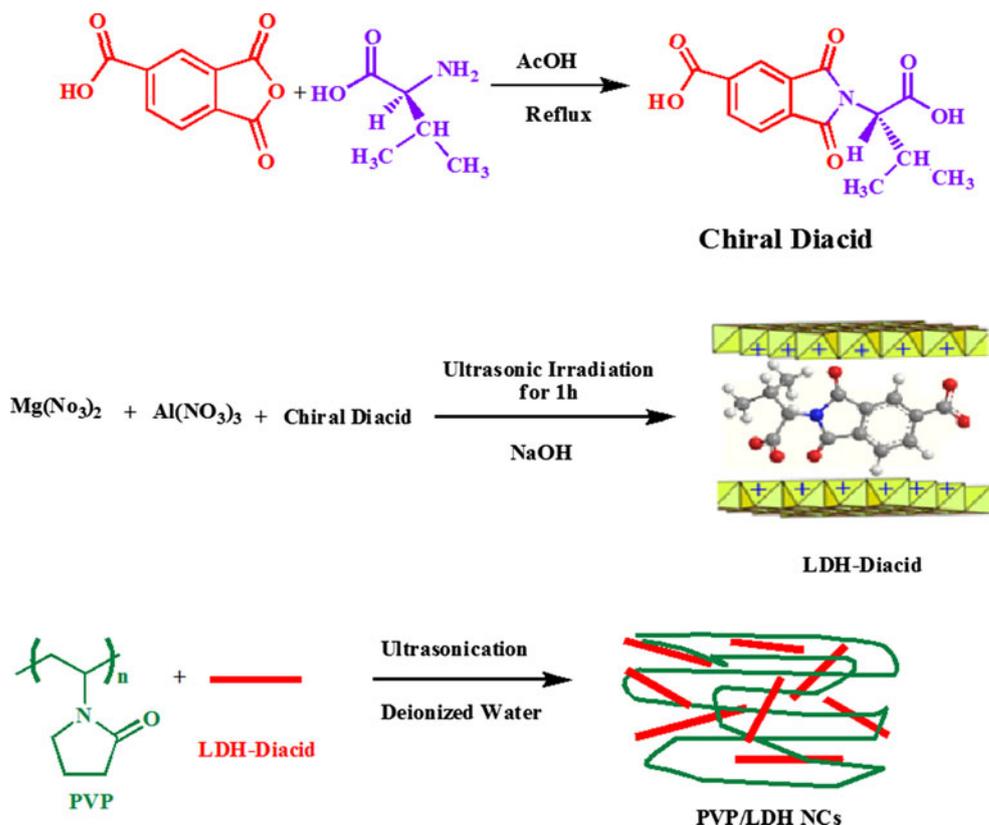
Since PVP has a strong tendency to form hydrogen bonding with other species containing highly electronegative groups, this biodegradable compound was used for synthesis of new hybrid materials. The adsorption of PVP onto surfaces of LDH-diacid is presumed to occur through hydrogen bonding. Apart from hydrogen bonding, van der Waals forces between polymer segments and the modified LDH surface would also play an important role in the overall adsorption process (Fig. 1).

## Characterizations

### FT-IR study

FT-IR spectra of LDH-CO<sub>3</sub><sup>2-</sup>, chiral diacid and LDH-diacid are represented in Fig. 2. In the FT-IR spectrum of LDH-CO<sub>3</sub><sup>2-</sup>, a broad band in the 3,300–3,600 cm<sup>-1</sup> regions and 1,632 cm<sup>-1</sup> can be attributed to the O-H groups that are between the layers and are related to interlayer water molecules. The strong peak at 1,373, 630 cm<sup>-1</sup> and the shoulders at 872 cm<sup>-1</sup> and 1,045 cm<sup>-1</sup> are attributed to the stretching vibration of CO<sub>3</sub><sup>2-</sup> [38, 39]. The band characteristic to metal-oxygen bond stretching appears below 700 cm<sup>-1</sup>. The sharp bands around 780, 554 and 440–450 cm<sup>-1</sup> are caused by various lattice vibrations associated with metal hydroxide sheets. For *N*-trimellitylimido-*L*-valine, the peaks between 2,916 to 2,848 cm<sup>-1</sup> and 1,777–1,673 cm<sup>-1</sup> are related to the CH and C=O bonds, respectively. Also the bands observed at 1,387 and 732 cm<sup>-1</sup> correspond to the presence of the imide heterocycle ring. The FT-IR spectra of LDH-diacid show two

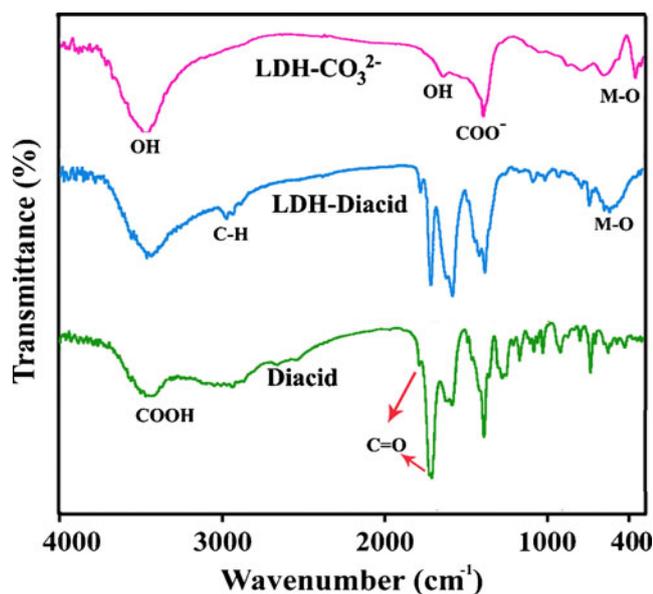
**Fig. 1** Preparation of chiral diacid, LDH-diacid and PVP/LDH-diacid NCs



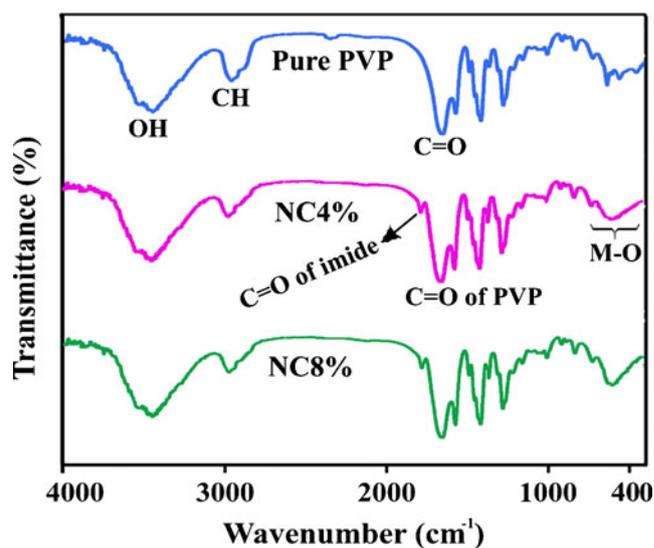
types of bands: one corresponding to the anionic diacid intercalated and other corresponding to the host LDH materials (Fig. 2). FT-IR spectrum for this compound show the peak at  $1,714$  and  $1,774\text{ cm}^{-1}$  can be attributed to the stretching vibration of  $C=O$ , confirming the presence of an imide ring related to diacid, which was not observed in  $LDH-CO_3^{2-}$

(Fig. 2). The appearance of characteristic bands for  $CO_3^{2-}$  indicates that still some  $CO_3^{2-}$  exist in the interlayer region, because carbonate ions could be adsorbed during the regeneration process from the atmospheric  $CO_2$  dissolved in the dispersion medium.

Figure 3 illustrated the FT-IR spectra of the pure PVP and the aforementioned NCs (2, 4, 8 wt.% of LDH-diacid). The



**Fig. 2** FT-IR spectra of the chiral diacid,  $LDH-CO_3^{2-}$  and LDH-diacid



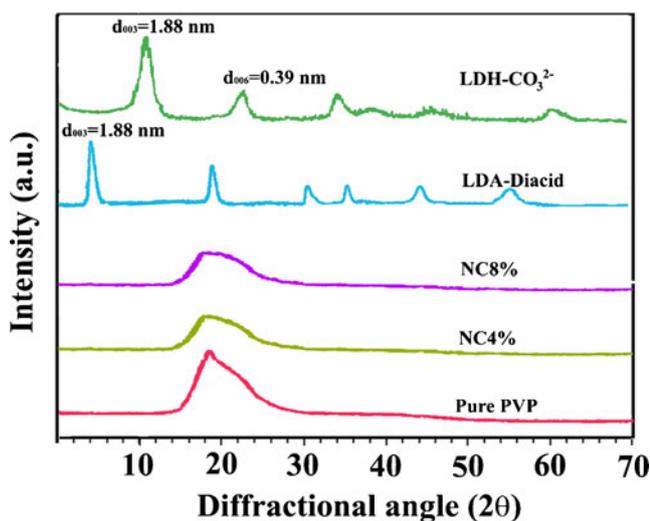
**Fig. 3** FT-IR spectra of the pure PVP and PVP/LDH-diacid NCs with 4 and 8 % of LDH-diacid

peak at  $1,646\text{ cm}^{-1}$  is corresponded to amide group of PVP which is a vibration absorption band formed by the combination of  $\text{C}=\text{O}$  and  $\text{C}-\text{N}$ . Because it is a combination, the peak is lower than that of the absorption peak of pure  $\text{C}=\text{O}$  ( $1,750\text{--}1,700\text{ cm}^{-1}$ ). The relatively broad  $\nu(\text{OH})$  stretching band centered at about  $3,450\text{ cm}^{-1}$  indicates the presence of stretching vibration associated with free and numerous hydroxyl groups (OH), in addition to hydrogen-bonded (H-O-H) due to residual water because of not using vacuum drying for the investigated samples. In NC4% and NC8% the presence of the typical bands of PVP and LDH-diacid are confirmed in this spectrum (Fig. 3).

### XRD patterns

One of the most common techniques used to elucidate the structure of polymer-clay systems is powder X-ray diffraction. XRD curves recorded for investigated samples are shown in Fig. 4. It shows diffractograms of LDH, LDH-diacid, PVP and NCs of PVP/LDH-diacid containing 4 and 8 wt.% of the modified LDH. The XRD spectrum of Mg-Al LDH shows that this compound has a highly crystalline nature and layered geometry. The position of the basal peak at  $2\theta=11.84$  indicates that the distance between two adjacent metal hydroxide sheets is about 0.76 nm. As expected, the position of the basal reflections of modified LDH is shifted to a higher  $d$  value indicating the expansion in the interlayer distance (Fig. 4). The XRD patterns of the LDH-diacid showed the expanding LDH structure with a sharp (003) spacing of 1.88 nm in Fig. 4.

Characteristic peak of LDH-diacid does not occur in diffractograms after incorporation of the modified LDH in polymer matrix. The only new broad diffraction peak appeared around  $2\theta=15\text{--}30$  correspond to the PVP polymer matrix. This peak diminishes as the concentration of LDH is



**Fig. 4** XRD patterns of the  $\text{LDH-CO}_3^{2-}$ , LDH-diacid, pure PVP, NC4% and NC8%

increased. This complete disappearance of LDH peaks may be due to the partially exfoliated structure, in which the gallery height of intercalated layers is large enough and the layer correlation is not detected by the X-ray diffractometer (Fig. 4). Although XRD provides a partial picture about distribution of nanofiller and disappearance of peak corresponding to  $d$ -spacing does not always confirm the exfoliated NCs, a complete characterization of NC morphology requires microscopic investigation.

### FE-SEM

The morphology of the  $\text{LDH-CO}_3^{2-}$  and LDH-diacid was investigated by FE-SEM (Fig. 5). The FE-SEM images of pure LDH revealed the nature of LDH particles, which roughly consists of plate-like shapes stacked on top of each other. The morphological feature of the LDH-diacid is similar to the unmodified LDH. It appears more floppy compared to unmodified LDH (Fig. 5c, d).

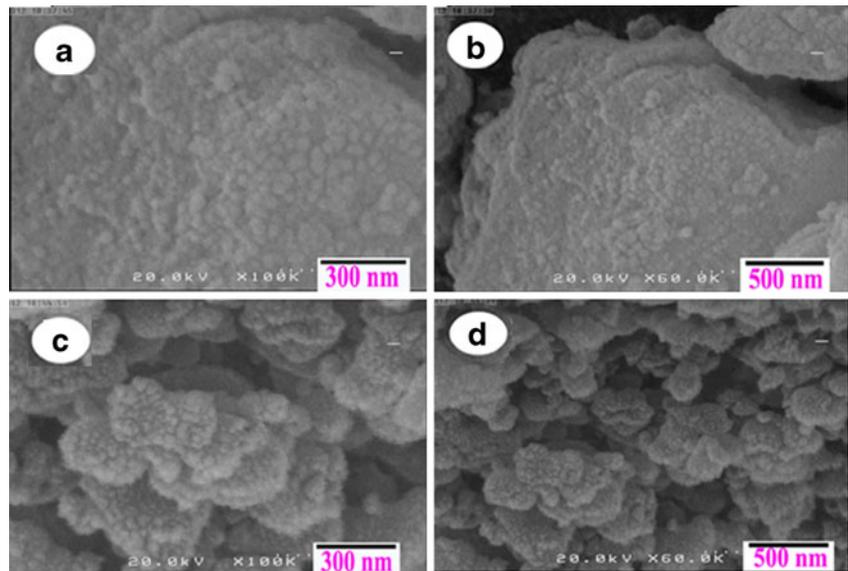
Figure 6 shows the FE-SEM images for PVP and the resulting NCs, with variation of the concentration of LDH-diacid. The PVP has a relatively uniform surface with a few spherical structures that are not clearly visible. Though, with the addition of LDH-diacid, the surface morphology of the NCs is changed as designated in Fig. 6. In the NCs, the micrograph exhibits the excellent dispersion of nano LDH-diacid into a PVP matrix. These observations are perhaps a result of modification of LDH with diacid. Thus, it may be suggested that the presence of LDH has a positive effect on PVP morphology, since the NCs exhibited a great transformation in morphology from typical crack PVP to a uniform particle pattern. Apparently, the particles are distributed uniformly in the polymer matrix.

### TEM

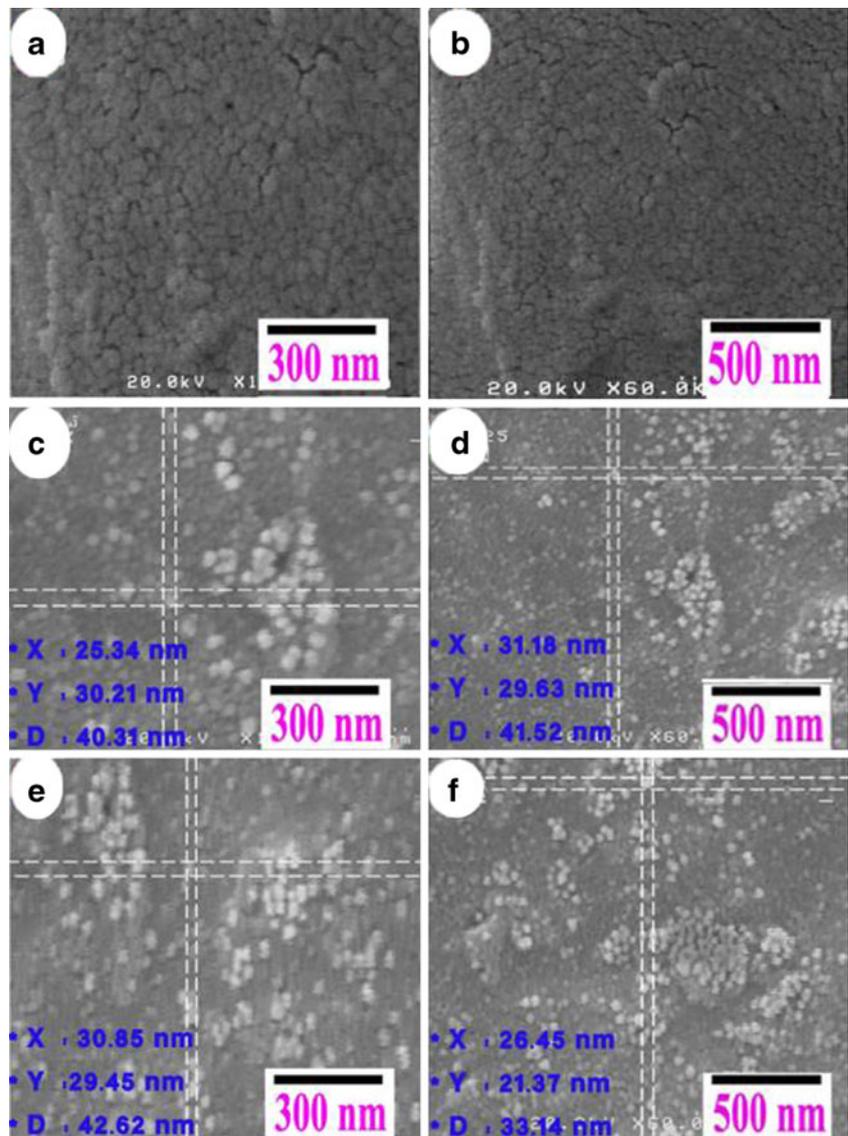
TEM presents an actual image of nanoclay platelets to permit recognition of internal morphology of nanohybrids. TEM images of  $\text{Mg}_2\text{Al-LDH-CO}_3^{2-}$  shows that the synthesized  $\text{CO}_3^{2-}/\text{LDH}$  are smooth, well-shaped in a hexagonal form, and overlapping crystals (Fig. 7a, b). After modification of LDH with chiral diacid, the hybrid nanoclays show well-defined hexagonal platelets with rounded corners. The sheets had a homogeneous contrast, reflecting their ultrathin nature and uniform thickness. There were no signs of aggregation visible in the micrographs (Fig. 7c and d).

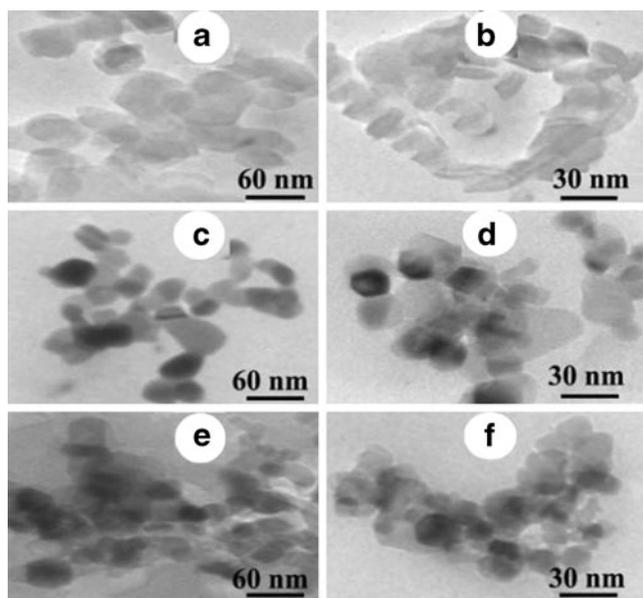
TEM presents an actual image of nanoclay platelets to permit identification of internal morphology of NCs. Typical TEM images of NC of PVP and 8 wt.% of LDH-diacid is shown in Fig. 7e and f. According to the TEM images, the sheets have homogeneous contrast, reflecting their ultrathin nature and uniform thickness. TEM observations reveal a

**Fig. 5** FE-SEM images of pure LDH (a, b), LDH-diacid (c, d)



**Fig. 6** FE-SEM photographs of pure PVP (a, b), PVP/LDH-diacid NC4% (c, d) and PVP/LDH-diacid NC8% (e, f)



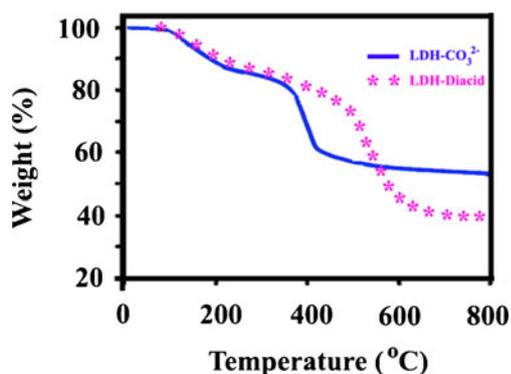


**Fig. 7** TEM micrographs of LDH-CO<sub>3</sub><sup>2-</sup> (a, b), LDH-diacid (c, d) and PVP containing 8 wt.% of LDH-diacid (e and f)

coexistence of organo-nanosilicate layers in the intercalated and partially exfoliated states.

Thermal degradation characteristics

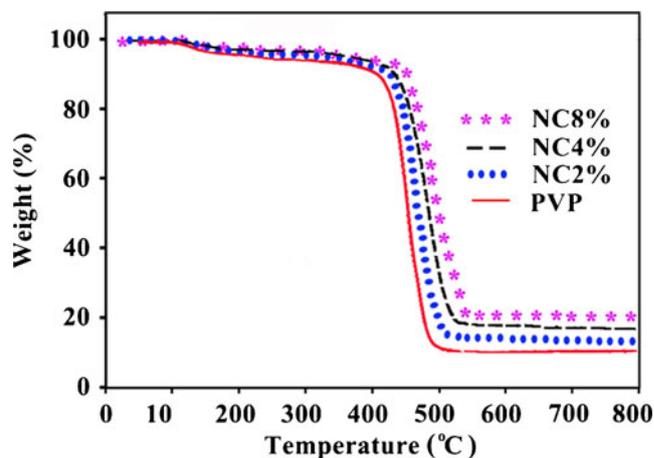
Comparison of the TGA curves of modified LDH with the unmodified one provides an indication of how the interlayer anions influence the decomposition of the host material. The TGA of LDH-CO<sub>3</sub><sup>2-</sup> and LDH-diacid are shown in Fig. 8. Thermal behavior of unmodified Mg-Al-LDH has been studied in detail by several researchers [38–41]. The most widely reported proposition suggests a two-stage decomposition process: a low temperature (up to about 225 °C) dehydration stage due to the loss of interlayer water and a high temperature decomposition (225–500 °C) stage due to the loss of interlayer carbonate and dehydroxylation of the metal hydroxide layer. The low temperature decomposition step in the unmodified LDH lies below 230 °C with decomposition peak around 210 °C. During this step, the loss of interlayer water molecules



**Fig. 8** TGA thermograms of LDH-CO<sub>3</sub><sup>2-</sup> and LDH-diacid

corresponds to a small loss in weight in the TGA plot. The high temperature decomposition of the unmodified LDH takes place in two distinct steps with decomposition peaks around 300 and 430 °C. The organic modification of the LDH changes its thermal decomposition behavior in comparison to the unmodified sample, especially the second stage of the decomposition process, which results in complete collapse of material structure [38–41].

The improvement of thermal properties compared to the unfilled polymer is a very important aspect of polymer/LDH NCs. LDHs contain a large amount of bound water due to the presence of an –OH group on the metal hydroxide sheets and some free water molecules in the interlayer region. The mechanism by which LDH clays improve the thermal stability and flammability of the polymer matrix is similar to that observed in the case of conventional metal hydroxide type fillers, like Mg(OH)<sub>2</sub> and Al(OH)<sub>3</sub> [42]. The endothermic decomposition of LDHs takes off heat from the surrounding environment and the liberated water vapor reduces the concentration of combustible volatiles in the vicinity of the polymer surface. As a result, the decomposition temperature of the polymer is increased. Figure 9 displays the TGA curves, and indicates the weight loss values for PVP and the obtained NCs. The TGA curves of the pure PVP take place during two-stage decomposition patterns. The first stage loss is perhaps triggered by the degradation of carbonic backbone and also the second stage is related to the degradation of the skeletal pyrrolidine structure. The thermal stability of the NCs of PVP and different amounts of LDH-diacid (2, 4 and 8 %) were also investigated by TGA under a N<sub>2</sub> flow. The NCs showed higher resistance towards thermal degradation. As can be seen from Fig. 9, PVP shows 9 % residue at 800 °C while the NC samples show 12–18 % residue at this temperature. It is notable that even small amounts of clay were effective in improving the weight residues of the hybrids.



**Fig. 9** TGA thermograms of PVP and PVP/LDH-diacid NCs

## Conclusions

The very exciting recent developments in intercalation reactions of LDHs show that this area of contemporary solid state chemistry has a very promising future. In particular, the ongoing work on the intercalation of biologically active guests has great potential. In this study, first, a chiral amino acid containing a diacid-modified LDH was synthesized by the co-precipitation method under fast and green conditions under ultrasonic irradiation. The XRD analysis of the LDH-diacid clays revealed that the surfactant anions were intercalated in the interlayer region of Mg-Al-LDH, thus enlarging the interlayer distance. Next, PVP/LDH-diacid NCs were synthesized with different compositions (0, 2, 4, and 8 wt.% of LDH-diacid) to study the effect of the LDH-diacid concentration on the properties of the PVP/LDH hybrids by a solution-intercalation method using ultrasound energy. The NC materials were investigated by TGA, XRD and FT-IR. The morphology of the LDH-diacid and PVP/LDH-diacid NCs was examined by FE-SEM and TEM and the results indicated that the LDH platelets are well-distributed within the PVP matrix. Thermal stability from TGA measurements was shown to be enhanced compared with those of pure PVP. The improvement of thermal properties was attributed to the homogeneity and dispersion of LDH-diacid in the polymeric matrix and the strong interaction between C=O groups of PVP and the oxygen atoms of silicate layers or carbonyl group as well as other polar groups of intercalated chiral dicarboxylated anions. Furthermore, Mg-Al-LDHs are naturally occurring minerals that can also be synthesized in the laboratory on a large scale by easy and safe methods to obtain more homogeneity in structure and compositions. Furthermore, LDH can be modified with a wide range of organic species. Such flexibility in selecting modifying anionic species makes LDH a suitable candidate for designing multifunctional nanohybrid fillers for polymers. The biocompatible nature of this organo-modified anionic clay is also suitable for designing environmentally friendly nanofillers that can be used in different areas. The improvement of LDH particle dispersion in a polymer matrix is certainly desired for further improvement in properties, especially thermal and mechanical.

**Acknowledgments** We gratefully acknowledge the partial financial support from the Research Affairs Division Isfahan University of Technology (IUT), Isfahan. The partial support of Iran Nanotechnology Initiative Council (INIC), National Elite Foundation (NEF) and Center of Excellency in Sensors and Green Chemistry (IUT) is also gratefully acknowledged.

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