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Short Communication

Thermally decomposed Ni-Fe-hydrotalcite: A highly active catalyst for the solvent-free N-acylation of different amines by acid chlorides

V.R. Choudhary *, D.K. Dumbre

Chemical Engineering and Process Development Division, National Chemical Laboratory, Pune, 411008, India

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ABSTRACT

A composite Ni–Fe catalyst obtained from the thermal decomposition of Ni-Fe-hydrotalcite at 600 °C shows very high activity in the solvent-free N-acylation of amines by different acid chlorides with high product yields under very mild reaction conditions (viz. room temperature, short reaction period and small amount of catalyst). The catalyst also shows excellent reusability in the reaction. The crystalline phases present in the catalyst are mixed oxides and hydroxides of nickel and iron. The high catalytic activity of the decomposed Ni-Fe-hydrotalcite is attributed to the formation of uniformly distributed Ni–Fe metal oxides and hydroxides.

1. Introduction

Acylation of amines is among the most widely used transformations in organic synthesis. N-acylated amines and their derivatives are widely used as starting materials for various organic transformations. The N-acylation of amines also provides an efficient and inexpensive means to protect their –NH groups in a multistep organic synthesis [1,2]. Earlier N-acylation was usually carried out using acylating agents, such as acid anhydrides or acyl chlorides in presence of organic bases [2–7]. This base catalyzed N-acylation is slow and requiring harsh and cumbersome procedures. As an alternative to basic catalysts, recently homogeneous Lewis acid (such as $ZnCl_2$, $FeCl_3$, $MoCl_5$, $B(C_6F_5)_3$[8] and anhydrous $NiCl_2$[9]) and iodine [10] have been reported for the N-acylation under solvent-free conditions. However, these homogeneous catalysts are difficult to remove from the reaction mixture and also cannot be reused. Hence they are not environmentally benign. Moreover, most of them need expensive acylating agent such as acid anhydride [8,9]. Heterogeneous catalysts, such as magnesium oxide [11] and yttria-zirconia [12], have also been reported for the N-acylation of amino compounds. However, although these catalysts can be easily separated, they require solvent and/or harsh reaction conditions (higher temperature and/or higher reaction time). Non-catalytic procedure for N-acylation at room temperature has also been reported [13]. But in this case, the acylation period is very long and, moreover, the reaction involves the use of ethyl acetate (as a solvent) and expensive acid anhydride. Hence there is a genuine

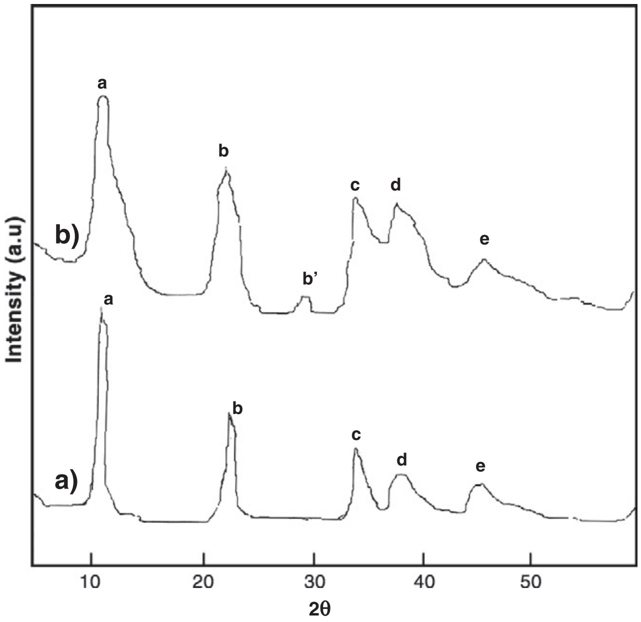

Fig. 1. XRD spectra of catalyst obtained from the thermal decomposition of a) Ni-Fe-HT and b) Ni(II)-Fe(III) nitrates, at 600 °C [Crystalline phases: a) $Fe(OH)_3$, b) $Ni(OH)_2$, c) Nioxide-OH-Fe, d) NiO, e) Ni-Fe-Oxide and b') Fe_2O_3].

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* Corresponding author. Tel.: +91 20 25902318; fax: +91 20 25902612.
E-mail addresses: vr.choudhary@ncl.res.in, vrc0001@yahoo.co.in (V.R. Choudhary).

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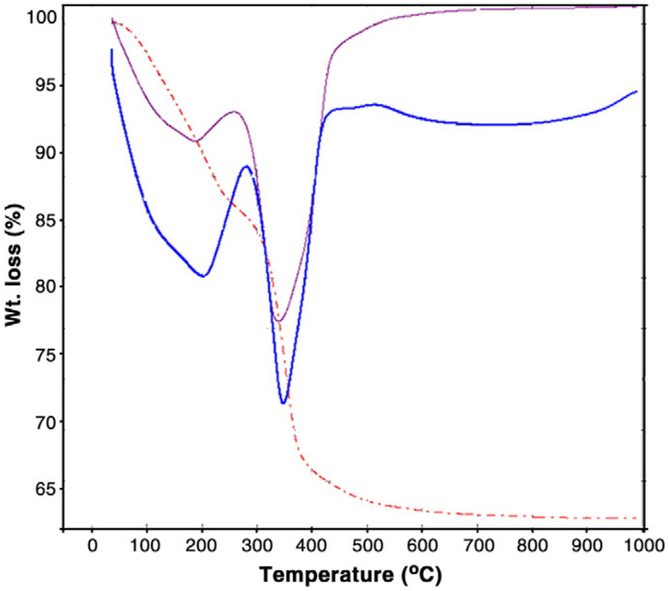


Fig. 2. TG, DTG and DTA of the Ni-Fe-hydrotalcite.

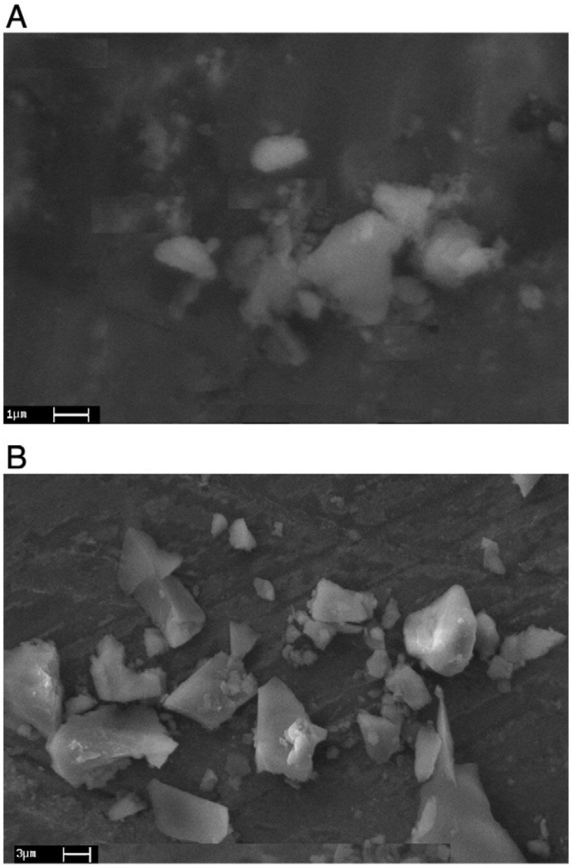


Fig. 3. SEM Photograph of catalyst obtained from the thermal decomposition of a)Ni-Fe-HT and b) physically mixed Ni(II)-Fe(III) nitrates (Ni/Fe = 3)at 600 °C.

need for developing a simple but rapid and environmentally benign method for the N-acylation of amines.

In this paper we report a solvent-free rapid selective N-acylation of aliphatic, cyclic and aromatic amines with inexpensive acid chlorides at room temperature using a highly active solid catalyst derived from Ni-Fe-hydrotalcite. The catalysts can be easily separated and reused several times in the reaction.

2. Experimental

The solid catalyst used in this investigation was obtained from the thermal decomposition of Ni-Fe-hydrotalcite (Ni/Fe mole ratio of 3.0) in a muffle furnace at 600 °C for 4 h. The resulting mass was finely powdered. The preparation and characterization of Ni-Fe-hydrotalcite have been given in our earlier publications [14,15].

The catalyst was characterized for crystalline phases by XRD (using a Phillips Diffractometer (1730 series) and CuK∝ radiations), particle/crystal size by SEM (using Stereo Scan 440 made in Cambridge UK). Its formation was studied by the thermal analysis (TG, DTG and DTA) of the Ni-Fe-hydrotalcite from 100 °C to 1000 °C at a linear heating rate of 20 °C/min in air (using Diamond TG/DTA).

The catalytic N-acylation reaction was carried out in a magnetically stirred round bottom flask (capacity: 25 cm^3), at the following reaction conditions: reaction mixture = 5 mmol amine + 7 mmol acid chloride + catalyst (10 wt.% w.r.t. amine) at room temperature (300 K) and reaction time = 1–30 min. Reaction was monitored by TLC. After completion of the reaction, the catalyst was separated by filtration and the filtrate was treated with a saturated solution of sodium bicarbonate, followed by extraction with ethyl acetate to give the crude product, which was subsequently purified by column chromatography on silica gel with petroleum ether/ethyl acetate as eluent. The catalyst was further washed with acetone, dried and reused. The reaction product was isolated by column chromatography and was confirmed by NMR spectroscopy.

3. Results and discussion

3.1. Catalyst formation and characterization

The catalyst was obtained from the thermal decomposition of Ni-Fe-HT (Ni/Fe = 3, CO_3^{2-} concentration = 0.66 mmol/g, surface area = 60 m^2/g) [14] at 600 °C. The XRD of the catalyst (Fig. 1a) revealed that the hydrotalcite structure is totally destroyed after decomposition of the Ni-Fe-hydrotalcite. The main crystalline phase present in the catalyst were found to be uniformly distributed $Fe(OH)_3$, $Ni(OH)_2$, Ni-oxide-OH-Fe, NiO and Ni-Fe-Oxide. The phases are expected to be uniformly distributed in the catalyst.

In order to study the catalyst formation, the Ni-Fe-HT was subjected to thermal analysis from 100 °C to 1000 °C. The TG, DTG and DTA graphs for the same are presented in Fig. 2. The TG, DTG and DTA curves indicate that the decomposition is endothermic and it occurs in two distinct steps- step-I between 100 °Cand 300 °C, with the DTG and DTA peaks at 185 °C and 200 °C, respectively, and step-II between 300 °C and 900 °C, with the DTG and DTA peaks at 330 °C and 340 °C, respectively. The weight loss in step-I and step-II was about 16% and 67.5%, respectively. The weight loss up to the temperature of 400 °C was quite fast. The weight loss in step-I is expected due to loss of physically adsorbed water in the hydrotalcite. Whereas,

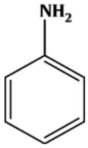
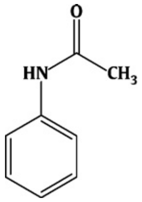
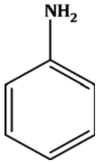
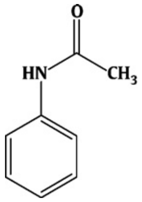
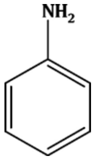
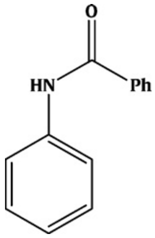
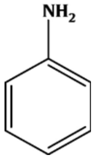
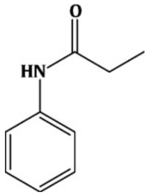
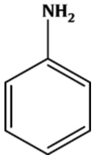
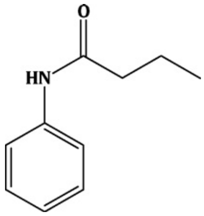
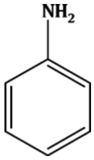
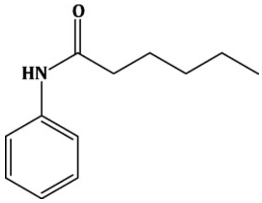
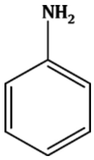
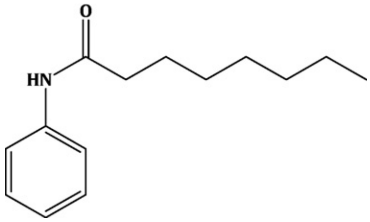
$$R_1\text{-}NH_2 + \quad R_2\text{-}COCl \xrightarrow[\text{Solvent-free, RT, 1-7min (-HCl)}]{\text{Thermally decomposed Ni-Fe-HT}} R_1\text{-}NHCOR_2$$

$$[R_1 = \text{alkyl, aryl or benzyl and } R_2 = \text{alkyl or aryl}]$$

Scheme 1. N-acylation of amines.

Table 1

N-acylation of amines with different acid chlorides at room temperature using thermally decomposed Ni-Fe-HT catalyst, under solvent-free condition.

Entry	Substrate	Acid chlorides	Product	Reaction time (min)	Isolated product yield (%)
1	2	3	4	5	6
1		CH_3COCl		1	95
2		CH_3COCl		1	97[a]
3		C_6H_5COCl		4	95
4		CH_3CH_2COCl		1	89
5		$CH_3CH_2CH_2COCl$		2	91
6		$CH_3(CH_2)_3CH_2COCl$		4	91
7		$CH_3(CH_2)_5CH_2COCl$		4	89

(continued on next page)

Table 1 (*continued*)

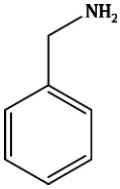
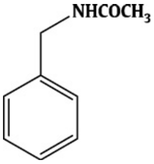
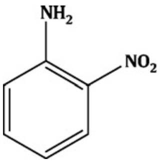
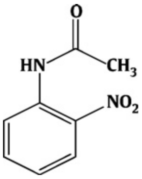
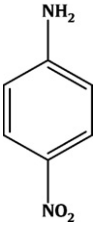
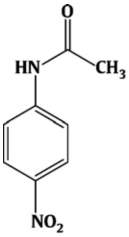
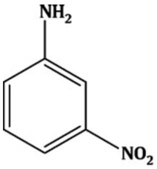
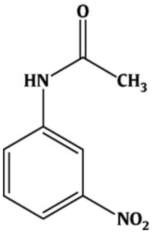
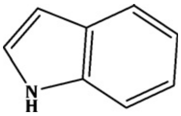
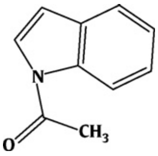
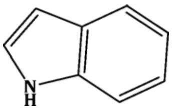
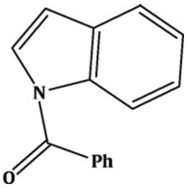
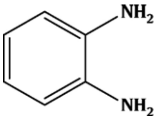
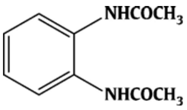
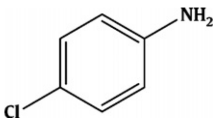
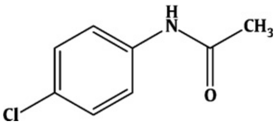
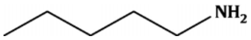
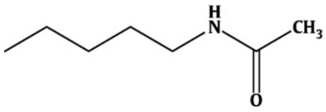
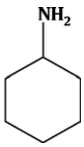
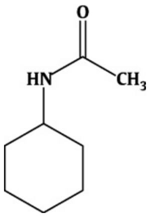
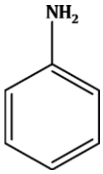
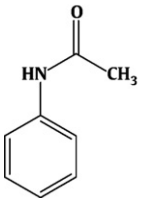
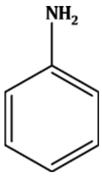
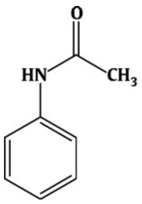
Entry	Substrate	Acid chlorides	Product	Reaction time (min)	Isolated product yield (%)
1	2	3	4	5	6
8		CH_3COCl		2	88[a]
9		CH_3COCl		4	88[a]
10		CH_3COCl		3	87[a]
11		CH_3COCl		4	87[a]
12		CH_3COCl		4	89[a]
13		C_6H_5COCl		6	85[a]
14		CH_3COCl		5	78[a]
15		CH_3COCl		5	80[a]

Table 1 (*continued*)

Entry	Substrate	Acid chlorides	Product	Reaction time (min)	Isolated product yield (%)
1	2	3	4	5	6
16		CH_3COCl		7	87[a]
17		CH_3COCl		7	70[a]
18		CH_3COCl		1	64[b]
19		CH_3COCl		1	68[c]

[a] AcCl (3.0 eq.) was used.

[b] Ni-Fe-HT without decomposition was used.

[c] Catalyst obtained from the decomposition of a mixture of Ni(II) nitrate and Fe(III) nitrate (with Ni/Fe mole ratio of 3.0) at 600 °C for 4 h.

the weight loss in step-II is expected due to the decomposition of the hydrotalcite, leading to a fast evolution of CO_2 at the lower temperatures (300 °C to 400 °C) followed by a slower dehydroxylation at the higher temperature (above 400 °C). The presence of different crystalline phases in the catalyst is consistent with this.

The catalyst has also been characterized for its particle/crystal size by SEM (Fig. 3a). Its crystal size varies from about 0.1 to 2 μm.

Since Ni(II) and Fe(III) are uniformly distributed in the hydrotalcite, both of them are also expected to be uniformly distributed in the decomposition product (i.e. the catalyst) from the hydrotalcite.

3.2. Catalytic N-acylation of amines

Results of the N-acylation of different aliphatic, cyclic and aromatic amines by different acid chlorides over the catalyst at room temperature under solvent-free condition (Scheme-1) have been presented in Table 1. The catalyst showed very high activity and selectivity in all the cases. The time required for completing the acylation is, however, found to be dependent upon the acylating agent and/or the substrate, as follows:

- The acetylation by acetyl chloride is much faster than the benzoylation by benzoyl chloride (entries 1 and 3).
- The acylation is slower with increasing the hydrocarbon chain length of the acid chloride (entries 1, 4–7).
- As expected the electron withdrawing group (NO_2) on the benzene ring causes a large decrease in the acylation rate (entries 9–11).
- The acylation of cyclic amine is slower (entries 1, 12, 13).
- The increase in the relative concentration of acetyl chloride results in a higher product yield (entries 1, 2). This is expected because of the high volatility of acetyl chloride.

It may be noted that, when the Ni-Fe-HT was directly used as a catalyst, the product yield in the same period was much smaller (entry 18). This is expected because of the very strong adsorption of acetyl chloride on the highly basic hydrotalcite [14]. Also, when the thermally decomposed (under similar conditions) mixed Ni–Fe nitrates were used as the catalyst in the acylation, the product yield was much smaller (entry 19). This may be due to the formation of solid catalyst with non-uniform distribution of Ni(II) and Fe(III) and/or the presence of Fe_2O_3 (which found to be absent in the decomposition product of the Ni-Fe-HT) in this catalyst. [Fig. 1a, b].

It may also be noted that the catalyst derived from the Ni-Fe-HT can be easily separated from the reaction mixture. It also shows

Table 2
Reuse of the Ni-Fe-HT catalyst in the N-acetylation of aniline with acetyl chloride.

Reuse of catalyst	Reaction time (s)	Isolated product yield (%)
First reuse	60	95
Second reuse	60	95
Third reuse	61	95
Fourth reuse	63	94
Fifth reuse	65	94

excellent reusability in the N-acylation; even in the fifth reuse, it does not loose its initial activity (Table 2). The observed small increase in the reaction time is expected mostly due to loss of catalyst during its processing. Thus, this catalyst is much superior to the earlier reported homogeneous catalysts [8–10]. It also shows much higher activity, requiring much lesser reaction time and/or temperature in the N-acylation, than the earlier reported heterogeneous catalysts [11,12].

4. Conclusions

The thermally decomposed Ni-Fe-hydrotalcite (Ni/Fe = 3) at 600 °C is a versatile catalyst showing very high activity and selectivity in the N-acylation of different aliphatic, cyclic and aromatic amines with different acid chlorides under solvent-free conditions at room temperature in a relatively very short period (within 1 to 7 min), the product yields are quite high (80–97%). The catalyst is environmentally benign; it is easily separable and reusable without the loss of its activity. Moreover, the acylation agents used in this process are relatively inexpensive as compared to the commonly used acid anhydrides. This protocol is particularly very useful for protecting the sensitive –NH group(s) of different amines in the organic synthesis process. It is environmentally greener than that uses solvent and/or catalyst which can not be easily separated and reused in the reaction.

Acknowledgements

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