Accepted Manuscript

Preparation and characterization of functionalized graphene oxide Cu (I) complex: A facile and reusable nanocatalyst for microwave assisted heterocyclization of alkyl halides with alkynes and sodium azide

Hossein Naeimi, Rahele Shaabani

| PII: | S1566-7367(16)30291-6 |
|----------------|-----------------------------------|
| DOI: | doi: 10.1016/j.catcom.2016.08.034 |
| Reference: | CATCOM 4764 |
| To appear in: | Catalysis Communications |
| Received date: | 9 July 2016 |
| Revised date: | 17 August 2016 |
| Accepted date: | 19 August 2016 |



Please cite this article as: Hossein Naeimi, Rahele Shaabani, Preparation and characterization of functionalized graphene oxide Cu (I) complex: A facile and reusable nanocatalyst for microwave assisted heterocyclization of alkyl halides with alkynes and sodium azide, *Catalysis Communications* (2016), doi: 10.1016/j.catcom.2016.08.034

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Preparation and characterization of functionalized graphene oxide Cu (I) complex: A facile and reusable nanocatalyst for microwave assisted heterocyclization of alkyl halides with alkynes and sodium azide

Hossein Naeimi*, Rahele Shaabani

Department of Organic Chemistry, Faculty of Chemistry, University of Kashan, Kashan, 87317-51167, I.R. Iran; Tel: 98-31-55912388; Fax: 983155912397; E-mail: naeimi@kashanu.ac.ir

Abstract

In this research, preparation of functionalized graphene oxide copper (I) complex first involves a reaction of carboxylic groups on graphene oxide with the amino groups on 1,7-heptandiamine and isotoic anhydride, and subsequently treatment with copper iodide. The formed complex was characterized by Fourier transform infrared spectroscopy (FT-IR), X-ray diffraction spectroscopy (XRD), energy dispersive X- ray (EDX) and field emission scanning electron microscopy (FE-SEM) techniques. 1,2,3-triazoles were synthesized from reaction of alkyl halides, alkynes and sodium azide catalyzed by functionalized graphene oxide copper (I) complex under microwave irradiation in excellent yields. This procedure eliminates the need to handle organic azides.

Keywords: Gaphene oxide, 1,2,3-triazole, Heterogeneous catalyst, Microwave irradiation Three component

Introduction

Among the various five-membered heterocyclic compounds, 1,2,3-triazoles are important and significant due to their wide range of applications including use as pharmaceutical agents, agrochemicals, industrial applications such as dyes, corrosion inhibition, photostabilizers, and photographic materials [1].

Among the best-known examples of triazole-containing structures is tazobactam, a β lactamase inhibitor that is marketed in combination with the broad spectrum antibiotic piperacillin. Tazobactam (I) and related triazole-containing compounds (II and III, Fig. 1)

turned out to be potent β -lactamase inhibitors with higher potency than clavulanic acid and sulbactam, and the triazole ring appears to play a pivotal role for its potency [2].



Fig. 1. Examples of triazole-containing

Numerous synthetic methods for the preparation of 1,2,3-triazole derivatives have been developed. Among them, Cu (I)-catalyzed azide-alkyne [3] cycloaddition (CuAAC) [4,5] reaction is the most efficient way to assemble the 1,2,3-triazole ring. Generally, copper (I) salts and ligands have been used as homogeneous catalyst systems to catalyze one-pot multi-component synthesis of 1,2,3-triazoles from benzyl/alkyl halides, alkynes and sodium azides [6]. Homogeneous catalysts suffers from many problems such as: difficult separation and recycling the expensive catalyst, cytotoxicity and environmental pollution. In order to overcome these problems, it has already used many heterogeneous catalysts in the wide range of organic reactions [7,8]. The heterogeneous catalysts offer several advantages, such as easy recovery, easy recycling, and enhanced stability [9]. Charcoal [10], zeolites [11], montmorillonite [12], NHC-modified silica [13], polystyrene [14] or chitosan [15] are some of the supports used for copper (I) in the heterogeneous version of the title click reaction. Moreover, the carbon materials have been widely used as heterogeneous catalysts. Catalysts based on carbon materials, such as activated carbon and carbon nanotubes, have also been studied as CuAAC catalyst supports [16].

Recently, graphene, graphene oxide and graphite have attracted enormous interest in the development of composite materials and catalysts [17-21], due to their remarkable physical, chemical and electrical characteristics, including a very high specific surface area [22].

In this report, we describe a convenient and efficient advancement microwaveaccelerated of one-pot synthesis of 1,4-disubstituted 1,2,3-triazoles from in-situ-generated azides, terminal alkynes and functionalized graphene oxide copper (I) complex as an efficient recyclable catalyst.

Experimental

General procedure for the synthesis of GO-NH-IA-Cu (I) complex

Graphene oxide was prepared using a modification of Hummers and Offeman's method [23].

Typically, GO (0.5 g) was suspended in SOCl₂ (30 mL) and 10 mL of DMF was added and subsequently, the reaction mixture was refluxed at 70 °C for 24 h. The resultant solution was filtered and washed with anhydrous tetrahydrofuran (THF) and dried under vacuum, the GO-COCl was obtained.

In the next step of catalyst preparation, GO–COCl (0.4 g) was suspended in 1,7-heptandiamine and 25 mL DMF was added and subsequently, the reaction mixture was refluxed at 70 $^{\circ}$ C for 24 h. The resultant solution was filtered and washed with ethanol to ensure that the excess diamine was completely removed. Finally, the products were dried at 70 $^{\circ}$ C under vacuum.

In continuation, GO-CO-NH₂ (0.36 g) and isotoic anhydride (0.36 g) was suspended in 30 mL ethanol was added and subsequently, the reaction mixture was at refluxed 60 $^{\circ}$ C for 24 h. The resultant solution was filtered and washed with ethanol to ensure that the excess

isotoic anhydride was completely removed. Finally, the products were dried at 70 $^{\circ}$ C under vacuum.

In the final of catalyst preparation, GO-CO-NH-IA (0.35 g) and copper iodide (0.35 g) was suspended in 30 mL acetonitrile was added and subsequently, the reaction mixture was at refluxed at 60 $^{\circ}$ C for 18 h. The resultant solution was filtered and washed with acetonitrile to ensure that the excess copper iodide was completely removed. Finally, the products were dried at 70 $^{\circ}$ C under vacuum, the pure complex was obtained.

For synthesis of 1,2,3-triazoles, alkyne (1mmol), alkyl halide (1 mmol) and NaN₃ (1.2 mmol) followed by adding GO-NH-IA-Cu(I) as catalyst in a 10.0 mL round-bottomed flask (H₂O-Ethanol, 6.0 mL). The mixture was treated under microwave irradiation (MW, 100 W). The progress of the reaction was monitored by TLC. After completion of the reaction, the catalyst was isolated by filtration through celite and the product was extracted with EtOAc (3 \times 10 mL). The products were characterized by ¹H NMR, ¹³C NMR, FT-IR and melting points and the spectral data of synthesized compounds were compared with authentic samples and confirmed [24-30].

1-Benzyl-4-phenyl-1H-1,2,3-triazole (Table 4, **3a**); White solid, m.p = 125-127 °C (Lit. [24]. 128-130 °C); IR (KBr) v (cm⁻¹): 3139 (C=C-H), 2924 (-C-H), 1607 (C=C), 1456, 1353 (C-N), 1218, 1073, 1046; ¹H NMR (CDCl₃, 400 MHz) δ (ppm): 5.58 (s, 2H, CH₂), 7.32 (m, 3H, H_{aromatic}), 7.40 (m, 5H, H_{aromatic}), 7.67 (s, 1H, H_{triazole}), 7.80-7.82 (d, *J*=8.0 Hz, 2H, H_{aromatic}); ¹³C NMR (CDCl₃, 100 MHz) δ (ppm): 54.21, 119.57, 125.71, 128.06, 128.17, 128.78, 128.82, 129.16, 130.58, 134.74, 148.22.

Results and discussion

In order to prepare the catalyst, at first graphene oxide was prepared according to the modified Hummer's method. The obtained GO was treated with thionyl chloride in DMF at

reflux temperature for 24 hours to generate GO–COCl and subsequently reacted with 1,7heptandiamin to yield amino-modified graphene oxide (GO-CO-NH₂). The obtained aminomodified graphene oxide was then treated with isotoic anhydride in ethanol at reflux temperature for 24 hours to generate (GO-CO-NH-IA). Finally, the GO-CO-NH-IA was treated with CuI in acetonitrile at reflux temperature for 18 hours. The catalyst was characterized using various techniques.

Fig. 2 shows the FT-IR spectra of GO, GO–COCl, GO-NH₂, GO-NH-IA. In the FT-IR spectrum of GO, the peaks at 3349, 1719, 1580 and 1064 cm⁻¹ correspond to the O–H, C=O, C=C and C–O stretching vibration, respectively. In the FT-IR spectrum of GO–COCl (Figure 4b), the relative intensity of the C=O stretch of the –COOH group at 1730 cm⁻¹ has significantly decreased, that confirmed the most carboxyl group functionalities have been transformed into the acyl chloride.



Fig. 2. FT-IR spectra of a) GO, b) GO-CO-Cl, c) GO-NH₂ and d) GO-NH-IA

To optimize the reaction conditions for the formation of 1,4-disubstituted 1,2,3triazoles from alkyl halide, alkyne and sodium azide, we devoted our efforts on this research using the reaction of phenylacetylene, benzyl chloride and NaN₃ in the catalytic amount of GO-NH-IA-Cu (I) as a simple reaction. The reaction was carried out in the presence of different quantities of the catalyst in water-ethanol (Table 1). It was found that the best result was obtained when the reaction was carried out in the presence of 0.005 g of catalyst (Table 1, entry 3). The usage of higher amounts of catalyst did not increase the yields significantly.

| Entry | Catalyst (g) | Time (min) | Yield (%) ^a | |
|-------|--------------|------------|------------------------|--|
| 1 | 0 | 120 | 0 | |
| 2 | 0.002 | 15 | 85 | |
| 3 | 0.005 | 10 | 88 | |
| 4 | 0.01 | 12 | 88 | |
| 5 | 0.015 | 14 | 88 | |
| | | | | |

| Table 1. Optimization of catalyst for synthesis | s of 1,2,3-triazole |
|---|---------------------|
|---|---------------------|

^aIsolated yields

Reaction conditions: 1 mmol phenylacetylene, 1 mmol benzyl chloride, 1.2 mmol NaN₃ (0.005) catalyst were added to the selected solvent (6 mL) under 100 W microwave irradiation at 80 $^{\circ}$ C temperature

In order to verify the effect of solvent, the model reaction was carried out in the presence of different solvents. The corresponding results are shown in Table 2. The best solvent was mixture of water and ethanol (1:1), which was resulted in higher yield and shorter reaction time in compared to the other used solvents (Table 2, entry 4).

| Table 2. Effect of various solvent on synthesis of 1,2,3-triazole | | | | |
|---|--|------------|------------------------|--|
| Entry | Solvent | Time (min) | Yield (%) ^a | |
| 1 | CH ₃ CN | 20 | 50 | |
| 2 | H ₂ O-CH ₃ CN(1:1) | 18 | 60 | |
| 3 | H_2O -Acetone(1:1) | 15 | 72 | |

PTFD MANU

| 4 | H ₂ O-EtOH(1:1) | 7 | 88 |
|---|----------------------------|----|----|
| 5 | H ₂ O-EtOH(2:1) | 10 | 80 |
| 6 | H ₂ O-EtOH(1:2) | 8 | 83 |
| 7 | EtOH | 10 | 82 |
| 8 | H ₂ O | 12 | 65 |

Reaction conditions: 1 mmol phenylacetylene, 1 mmol benzyl chloride, 1.2 mmol NaN₃, and (0.005 gr) GO-NH-IA-Cu (I) were added to the selected solvent (6 mL) under 100 W microwave irradiation at 80 °C temperature ^aIsolated yields

We further examined the effect of microwave power, and the irradiation time (Table 3) on the click reaction involving of phenylacetylene, benzyl chloride and NaN₃ in the catalytic amount of GO-NH-IA-Cu (I) under various powers of microwave irradiation (Table 3, entry 2). When higher powers are used degradation product is occurred that it lead to the decrease in product yields.

| Table 3. | Effect of | microwave | irradiation of | on synthesis of | 1,2,3-triazole |
|----------|-----------|-----------|----------------|-----------------|----------------|
|----------|-----------|-----------|----------------|-----------------|----------------|

| Entry | Power (W) | Time (min) | Yield (%) ^a |
|-------|-----------|------------|------------------------|
| 1 | - | 180 | 0 |
| 2 | 100 | 10 | 88 |
| 3 | 180 | 12 | 84 |
| 4 | 300 | 15 | 80 |

Reaction conditions: 1 mmol phenylacetylene, 1 mmol benzyl chloride, 1.2 mmol NaN₃, and (0.005 gr) GO-NH-IA-Cu (I) were added to the 1:1 mixture solvent of EtOH:H₂O as solvent (6 mL) under various microwave irradiation power. ^aIsolated yields

After optimization of the reaction conditions, this three-component reaction proceeds via in-situ formation of an alkyl azide from an alkyl halide and sodium azide. The alkyl azide then undergoes 1,3-dipolarcycloaddition reaction with terminal alkynes to give 1,4disubstituted 1,2,3-triazoles in high to excellent yields. Here, we describe a process in which GO-NH-IA-Cu (I) efficiently catalyzes azide-alkyne cycloaddition under microwave irradiation (Table 4).



Table 4. The GO-NH-IA-Cu (I) catalyzed three component synthesis of triazoles

In order to development and limitations of the general protocol, it was investigated the reaction using a variety of benzyl and alkyl halides and alkynes as the substrates under the same conditions. The related results are summarized in Table 4. As can be seen in this Table, the products were obtained in high to excellent yields and short reaction times for all of the entries.

We further explored the reusability of the catalyst in the model reaction with treatment of the benzyl chloride, the phenylacetylene, NaN_3 in the presence of 0.005 g of GO-NH-IA-Cu(I) catalyst under microwave irradiation (Figure 3). As can be seen from this figure, the catalyst can be used up to six cycles with slight decrease in the yield percentage. It also was observed that the catalyst showed excellent activity for the cycloaddition reaction even after the sixth cycle.



In the present work, we developed a new functionalized graphene oxide copper (I) complex as a heterogeneous catalyst in click reaction. It shows high catalytic activity for synthesis of triazoles under microwave irradiation. This efficient procedure can be applied to the synthesis of a wide variety of 1,2,3-triazoles in high to excellent yields. The advantages of catalyst are inexpensive nature, reusability and stability of the catalyst, simplicity of procedure and work up and green condition.

Acknowledgments

The authors are grateful to the University of Kashan for supporting this work by grant no. 159148/68.

References

[1] H. Dehne, in: Methoden der Organischen Chemie (Houben-Weyl), (Ed.: E. Schumann,), Thieme, Stuttgart, 1994, Vol. E 8d, pp 305–405.

[2] S.Yan, Y. Liu, Y. Chen, L. Liu, J. Lin, Bioorganic and Medicinal Chemistry Letters, 20 (2010) 5225–5228.

[3] X. Zhang, H. Li, L. You, Y. Tang, R. P. Hsung, Adv. Synth. Catal. 348 (2006) 2437–2442.

[4] V.V. Rostovtsev, L.G. Green, V.V. Fokin, K.B. Sharpless, Angew. Chem. 114 (2002) 2708–2711.

[5] L.D. Pachon, J.H. van Maarseveen, G. Rothenberg, Adv. Synth. Catal. 347 (2005) 811– 815.

[6] X.Q., Xiong, L., Cai, Z.K., Tang, Chin. J. Org. Chem. 32 (2012)1410-1428.

[7] H. Naeimi, Z.S. Nazifi, Appl. Catal. 477 (2014) 132-140

[8] R. Ghahremanzadeh, Z. Rashid, A.-H. Zarnani, H. Naeimi, Appl. Catal. 467 (2013) 270–278.

- [9] K. Kaneda, K. Ebitani, T. Mizugaki, K. Mori, Bull. Chem. Soc. Jpn. 79 (2006) 981-1016.
- [10] C.-T. Lee, S. Huang, B.H. Lipshutz, Adv. Synth. Catal. 357 (2009) 3139-3142.
- [11] S. Chassaing, A. Alix, T. Boningari, K.S.S. Sido, M. Keller, P. Kuhn, B. Louis, J. Sommer, P. Pale, Synthesis 9 (2010) 1557–1567.
- [12] I. Jlalia, H. Elamari, F. Meganem, J. Herscovici, C. Girard, Tetrahedron Lett. 49 (2008) 6756–6758.
- [13] P. Li, L. Wang, Y. Zhang, Tetrahedron 64 (2008)10825-10830.

[14] U. Sirion, Y.J. Bae, B.S. Lee, D.A. Chi, Synlett.15 (2008) 2326–2330.

[15] M. Chtchcigrovsky, A. Primo, P. Gonzalez, K. Molvinger, M. Robitzer, F. Quignard, F. Taran, Angew. Chem. 121 (2009) 6030–6034

[16] H. Sharghi, M.H. Beyzavi, A. Safavi, M.M. Doroodmand, R. Khalifeh, Adv. Synth. Catal. 351 (2009) 2391–2410.

[17] M. Fang, K. Wang, H. Lu, Y. Yang, S. Nutt, J. Mater. Chem. 19 (2009) 7098-7105.

[18] D.R. Dreyer, C.W. Bielawski, Chem. Sci. 2 (2011) 1233-1240.

- [19] Y.-F. Li, M.-Q. Guo, S.-F. Yin, L. Chen, Y.-B. Zhou, R.-H. Qiu, C.-T. Au, Carbon, 55 (2013) 269-275.
- [20] D.-H. Lan, F.-M. Yang, S.-L. Luo, C.-T Au, S.-F. Yin, Carbon, 73 (2014) 351-360.

[21] D.-H. Lan, L. Chen, C.-T. Au, S.-F. Yin, Carbon, 93 (2015) 22-31.

[22] M.J. Allen, V.C. Tung, R.B. Kaner, Chem. Rev. 110 (2010) 132-145.

[23] W.S. Hummers, R.E. Offeman, J. Am. Chem. Soc. 80 (1958) 1339-1339.

[24] S. Chassaing, A. Sani Souna Sido, A. Alix, M. Kumarraja, P. Pale, J. Sommer, Chem-Eur J. 14 (2008) 6713-6721.

[25] S.T. Abu-Orabi, M.A. Atfah, I. Jibril, F.M. Marii, A.A.-S. Ali, J. Heterocyclic, Chem. 26 (1989) 1461-1468.

[26] S.B. Otvos, I.M. Mandity, L. Kiss, F. Fulop, Chem-Asian J.8 (2013) 800-808.

[27] H. Naeimi, S. Dadashzadeh, M. Moradian, Res. Chem. Intermed. 5(2015) 2687-2695.

[28] Z. Gonda, Z. Novak, Dalton Trans. 39 (2010) 726-729.

[29] P. Appukkuttan, W. Dehaen, V.V. Fokin, E. van der Eycken, Org. Lett. 6 (2004) 4223-4225.

[30] T. Jin, M. Yan, Menggenbateer, T. Minato, M. Bao, Y. Yamamoto, Adv. Synth. Catal. 353 (2011) 3095-3100.

Graphical abstract



Highlight

- Developed a new functionalized graphene oxide copper (I) complex.
- Recoverable heterogeneous catalyst.
- High activity of the catalyst in the synthesis of 1,2,3-triazoles.
- Easy work-up of pure target products.
- Excellent product yields and Short reaction times.

A CLARENCE