

Cu-metformin grafted on multi walled carbon nanotubes: Preparation and investigation of catalytic activity

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Abstract

An efficient and one-pot procedure for the preparation of 1,4-disubstituted 1,2,3-triazoles derivatives from reactions of various aryl azides and different terminal alkynes in the presence of functionalized carbon nanotubes (CNTs) by metformin and subsequent coordination with copper(I) has been developed. The catalysts showed environmentally benign character, which can be easily prepared, stored, and recovered several times without obvious significant loss of activity.

Keywords: Carbon nanotubes; copper; metformin; 1,2,3-triazole; click reaction.

Introduction

Nanomaterials are attractive candidates as solid supports for the immobilization of well-defined homogeneous catalysts [1]. Because of their large surface area, which can carry high amounts of catalytically active species, these supported catalysts exhibit very high activity under mild conditions [2].

CNTs such as single-walled (SWCNT) and multi-walled (MWCNT) nanotubes have attracted significant interests because of their considerable mechanical [3], electrical properties [4], and thermal conductivity [5]. Moreover, their large surface area and excellent mechanical and chemical stability make them a potentially and ideally useful selection for various applications in electronics, optics, polymer composites, catalysis, and many others [6]. The

metal deposition on CNTs has provided more reliable utilities for these materials in an extensive applications range from solar cells, hydrogen storage, sensor devices, energy storage, and catalysis [7]. Thus, organic reactions are one of the potential areas in which CNTs as an appropriate solid support can be used.

Huisgen introduced 1,3-dipolar cycloaddition reaction of azides and alkynes [8]. This catalyst-free reaction normally produces both triazoles isomers (1,4- and 1,5) that makes it inappropriate for organic syntheses. In 2002, Meldal et al [9] and Sharpless et al. [10] reported the using of copper for this reaction under mild conditions called click reaction [11]. Recently, this method became a suitable way for the synthesis of triazoles using various homogenous and heterogeneous catalyst

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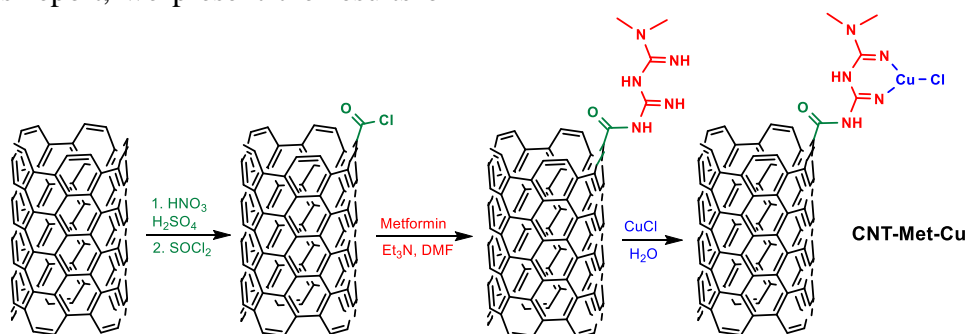
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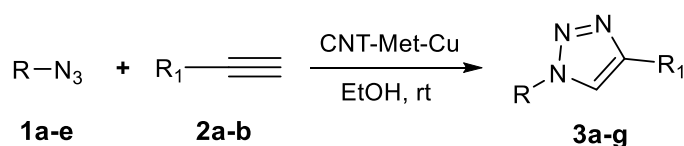
[12], such as $\text{Cu}(\text{OAc})_2$ [13], $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ [14], nano-sized CuO [15], silica supported Cu nanoparticles [16], nanomagnetic supported Cu nanoparticles [17], thiourea-supported copper(I) chloride [18] and copper/carbon nanoparticles [19]. Many of these methods have disadvantages that need to be addressed. Hence the using of new and green methods is still desirable and much in demand.

Recently, Veisi et al. functionalized CNTs by different ligands and metals [20]. In their previous work, they functionalized CNTs by metformin ligand and then copper chloride coordinated to amine groups of metformin ligand and Cu -metformin immobilized on CNTs has been prepared (CNT-Met-Cu).^[20a] Therefore, in this report, we present the results of

an extended investigation on the catalytic activity of the copper-metformin functionalized CNTs (CNT-Met-Cu) (Scheme 1), as an efficient and green catalyst for the synthesis of 1,4-disubstituted 1,2,3-triazoles derivatives. Easy separation and recyclability of the catalyst (up to five times) are the most important advantages of this system. To the best of our knowledge, there are no examples of the use of functionalized CNTs, especially CNT-Met-Cu as a catalyst for the synthesis of 1,2,3-triazoles derivatives from condensation of various aryl azides and different terminal alkynes. Therefore, we wish to report a simple, green and efficient synthetic method for synthesis of 1,2,3-triazoles derivatives using CNT-Met-Cu under mild conditions (Scheme 2).



Scheme 1. Synthesis of catalyst (CNT-Met-Cu)



Scheme 2. Synthesis of 1,2,3-triazole in presence of catalyst (CNT-Met-Cu)

Experimental

General

Melting points of the products were analyzed with an electrothermal type 9200 melting point apparatus. Transmission electron microscopy (TEM) was performed with a Leo 912AB (120 kV) microscope (Zeiss, Germany). Inductively coupled plasma optical emission spectroscopy (ICP-OES) analysis was carried out with a

Varian VISTA-PRO, CCD (Australia). Elemental compositions were determined with EDX analysis (model 7353, Oxford Instruments, UK), with 133 eV resolution.

General procedure for the preparation of 1,2,3-triazole derivatives 3a-g

CNT-Met-Cu catalyst (10 mg) in ethanol was added to a solution of azide (1.10 mmole), terminal alkyne (1.0 mmole) and the mixture was stirred at

room temperature for 15-30 min. The progress of reaction was monitored by TLC and upon the completion of the reaction, the reaction mixture was diluted with EtOAc and the catalyst was centrifuged, and separated from reaction mixture. The organic layer was dried over anhydrous Na_2SO_4 , followed by evaporation under reduced pressure to remove the solvent. The residue was purified by recrystallization from ethanol to afford corresponding 1,4-disubstituted 1,2,3-triazoles.

Results and discussion

The catalyst (CNT-Met-Cu) was prepared by the reaction of metformin and acylated CNTs and followed by coordination with CuCl onto the CNT-metformin according to procedures reported in the literature,[20a] (Scheme 2). For confirmation of catalyst preparation, the catalyst was fully

characterized using transmission electron microscopy (TEM), energy dispersive X-ray spectroscopy (EDS), thermogravimetric analysis and inductively coupled plasma (ICP).

Transmission electron microscopy (TEM) studies are carried out to observe the morphology, size and possible grafting of metformin groups on CNTs. The existence of metformin groups that covalently bonded on CNTs was clearly distinguishable as the identified spots in Figure 1. This result indicates that the metformin ligands were covalently grafted on CNTs surface. The EDS pattern of catalyst proves the elemental analysis of desired materials in the construction of the nano-catalyst such as Cu, Cl, O, N and C (Figure 2). This analysis confirms successful covalently immobilization of copper-metformin on the surface of CNTs.



Figure 1. TEM image of CNT-Met-Cu

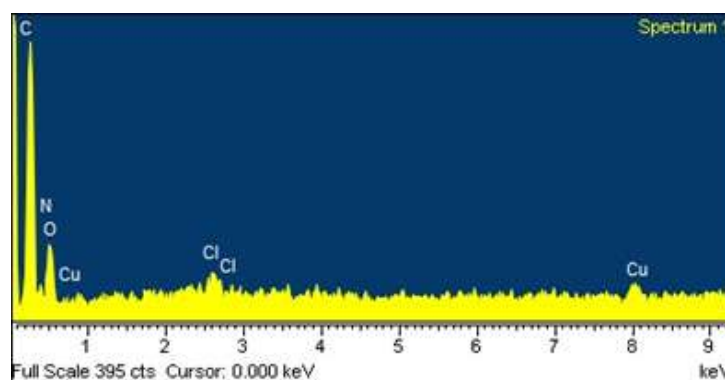


Figure 2. EDS pattern of CNT-Met-Cu

Thermogravimetric analysis as a powerful technique for estimating the functionalization percentage of CNTs surfaces was applied for confirmation the supported catalyst preparation. As shown in Figure 3, the final catalyst (CNT-Met-Cu) shows a weight loss about 10% below 300 °C resulted from removal of adsorbed water and functional groups on the surface of CNTs. Another weight loss about 35% from 300 to 700 °C is due to removal of

amino groups from CNT surfaces and probability of the composition of chemical structure of CNTs.

The exact amount of Cu (copper) in the prepared catalyst was studied with inductively coupled plasma (ICP) technique. According to ICP data, the weight percentage of Cu was 5.44 wt%. This characterization approves that copper successfully complexed with metformin ring.

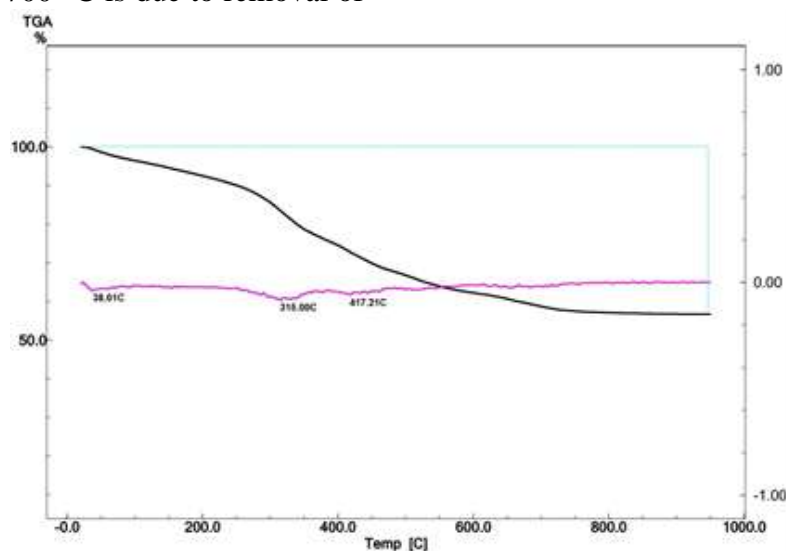


Figure 3. TGA of CNT-Met-Cu catalyst

In order to find the reaction conditions, the reaction of phenyl azide and phenyl acetylene was selected as a model reaction (Table 1). The results show that the reaction was not proceed in the absence of catalyst in solvent-free conditions even after 3 h (Table 1, Entry 1). The reaction was carried out in different polar and non-polar solvents and solvent-free condition in presence of 10 mg of catalyst (Table 1, Entries 2-8). Results show that the reaction was carried out better in polar solvents like methanol water and ethanol (Table 1, Entries 6-8) and the maximum yield was obtained in ethanol as a solvent (Table 1, Entry 8). With decreasing the temperature from reflux to room temperature, the yield of the reaction

was increased (Table 1, Entries 8-10). The best temperature was room temperature (Table 1, Entry 10). Finally, the amount of catalyst has been investigated. Thus, the best results were using 10 mg of catalyst at room temperature in ethanol (Table 1, Entry 10).

After finding optimization of the reaction conditions, the generality of this methodology has been studied in the reaction of various azide and different alkynes in presence of 10 mg of CNT-Met-Cu (Table 2). All aryl azides carrying either electron-donating or electron-withdrawing groups reacted successfully and gave products in high yields within short reaction time (15-30 min).

Table 1. Optimization of solvent, temperature and amount of catalyst

Entry	Conditions	Catalyst (mg)	Temp. (°C)	Time (min)	Yield (%) ^a
1	Solvent-free	----	rt	180	----
2	Solvent-free	10	rt	120	Trace
3	n-hexane	10	reflux	120	11
4	CHCl ₃	10	reflux	120	23
5	CH ₂ Cl ₂	10	reflux	120	20
6	H ₂ O	10	reflux	120	68
7	MeOH	10	reflux	120	70
8	EtOH	10	reflux	120	84
9	EtOH	10	50	60	88
10	EtOH	10	rt	15	94
11	EtOH	5.0	rt	15	90
12	EtOH	20	rt	15	90

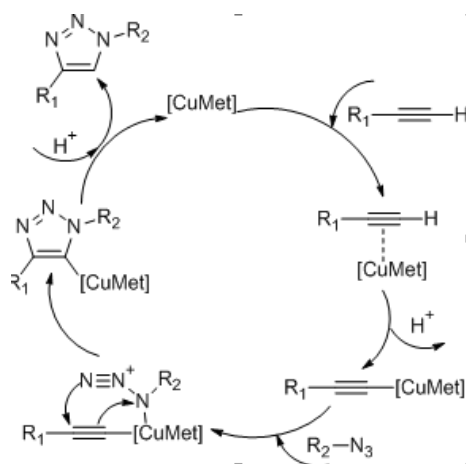
^a Based on isolated yield**Table 2.** Synthesis of 1,2,3-triazoles **3a-g** using CNT-Met-Cu as a catalyst ^a

Entry	R	R ₁	Product	Time (min)	Yield (%) ^b	Melting point (°C)	
						Found	Reported
1	Ph	Ph	3a	15	94	97-98	97-98 [21]
2	4-NO ₂ Ph	Ph	3b	15	95	255-256	254 [21]
3	4-BrPh	Ph	3c	18	91	232-234	232 [21]
4	4-CH ₃ Ph	Ph	3d	20	95	173-174	174 [21]
5	4-ClPh	Ph	3e	30	96	227-229	228 [21]
6	Ph	CH ₂ OH	3f	15	90	115-116	116-118 [22]
7	4-NO ₂ Ph	CH ₂ OH	3g	30	92	200-202	201-202 [22]
8	4-BrPh	CH ₂ OH	3h	15	88	134-135	135-137 [23]
9	4-CH ₃ Ph	CH ₂ OH	3i	30	89	124-125	124-125 [24]
10	4-ClPh	CH ₂ OH	3g	20	92	144-145	144-145 [25]

^a Reaction conditions: azides (**1a-c**; 1.0 mmol), terminal alkynes (**2a-b**; 1 mmol) and catalyst (10 mg) at room temperature in EtOH^b Isolated yields.

A proposed mechanism for the synthesis of 1,2,3-triazoles catalyzed by CNT-Met-Cu is shown in Scheme 3. In the first step, a terminal alkyne is coordinated to Cu in center of metformin ligand which activates the C-H bond and then, corresponding

copper-alkylidene complex is formed. In the second step, aryl azides react with copper-alkylidene intermediate, followed by intramolecular cyclization and finally produce five-member ring of triazole as a product.



Scheme 3. The proposed mechanism for the synthesis of 1,2,3-triazoles

The reusability of the catalyst (CNT-Met-Cu) was studied in model reaction. For this aim, after the completion of the reaction, the catalyst was isolated from reaction mixture using simple centrifuging and washed carefully with solvents (acetone and

water) to remove the residual product, dried at 80 °C under vacuum and reused in other reactions. The results showed the same activity as the fresh catalyst without any significant loss of its activity (Figure 4).

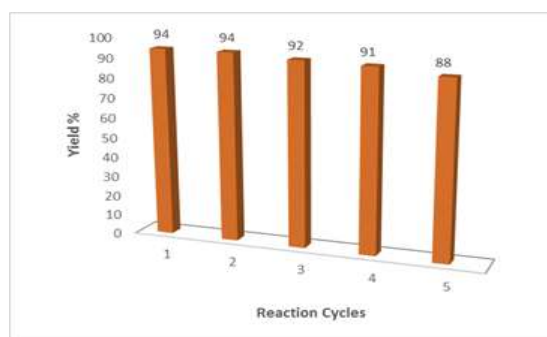


Figure 4. Reusability of catalyst for model reaction

To confirm the merit of our study, using of CNT-Met-Cu in the synthesis of 1,4-disubstituted 1,2,3-triazoles (phenyl azide and phenyl acetylene) with other heterogeneous catalysts were

compared (Table 3). Based on the obtained results, our catalyst shows a more satisfied catalytic activity in shorter reaction time and milder reaction conditions.

Table 4. The comparison of effect of CNT-Met-Cu catalyst with other heterogeneous catalysts in synthesis of 1,2,3-triazole **3a**

Entry	Catalyst	Solvent	Temp. (°C)	Time (min)	Yield (%) ^a	Ref.
1	Cu ^{II} -Hydrotalcite	MeCN	rt	360	86	[26]
2	AgN(CN) ₂	H ₂ O/EG	rt	120	95	[27]
3	CuSO ₄ /Urea	H ₂ O	rt	60	92	[14]
4	Cu(PPh ₃) ₂ NO ₃	Solvent-free	rt	40	96	[28]
5	Nano Cu/SiO ₂	DMSO	rt	25	97	[29][30]
6	CNT-Met-Cu	EtOH	rt	15	94	This study

^a Based on isolated yield

Conclusion

In conclusion, a green procedure was presented by preparation of covalently immobilization of copper-metformin on the CNTs and all characterization such as TEM, EDS and ICP confirmed the successful immobilization of Cu-Met on the surface of CNTs. The prepared catalyst has been carried out the synthesis of 1,4-disubstituted 1,2,3-triazoles in short reaction times and high yields under mild irradiation.

Acknowledgments

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