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Highly functionalized heterogeneous dendrigraft catalyst with peripheral copper moieties for the facile synthesis of 2-substituted benzimidazoles and 2, 2-disubstituted benzimidazoles

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Synthesis of Dendrigraft amidoamine polymer having glycerol initiated polyepichlorohydrin as core has been demonstrated on a Merrifield resin support to achieve the heterogeneous nature for catalytic applications. In earlier studies of supported dendritic systems, no effort was initiated to synthesize a dendritic polymer having high functionality in the low generation. The copper complexes of Gn (n= 0, 1, 2) dendrigraft polymer were found to be excellent catalysts for the synthesis of benzimidazole derivatives via the reaction between o-phenylenediamine with aldehydes. Aliphatic and cyclic ketones also showed excellant conjugation towards o-phenylenediamine. A detailed study of the synthesis of 2-substituted benzimidazoles and 2, 2-disubstituted benzimidazoles were done with dendrigraft G2 copper catalyst. The reusability of the catalyst is examined for five consecutive steps and showed no significant loss of catalytic activity for both the cases. The green attributes of the catalyst were:, final oxidation step was conducted using air, only small amount of catalyst was needed to drive the reaction and ethanol was used as the solvent under room temperature conditions.

1. Introduction

Recently, great attention has been directed towards the synthesis of Dendrigraft or Dendronized polymers.[1] Great amount of functionality can be achieved with these polymers in comparison with dendrimers. In the case of dendrigraft polymers,[2] polymers are grafted on another polymer and in dendronized polymer, the focal points of the dendrons are connected to the pending functional groups. This occurs at every repeating unit along the polymer backbone. The result is a special case of a graft copolymer, a comb polymer.[3] This has the peculiar feature that all of the side chains are dendrons. Polymers with this architecture are referred to as 'dendronized polymers, or 'denpols'.[4] These terms are generally assigned to polymers having linear type core. In the present context, it is expected that the term dendrigraft polymer is more appropriate here. This is because; dendrons are grafted on the polymeric chain whether linear or branched. This differs from the situation of grafting of polymeric chain as in the case of Tomalia's[3] or Gauthier's[5] dendrigraft polymer and it would be better to call dendronized polymer as dendrigraft or it can be grouped under the dendrigraft family. Most of the reported Dendronized polymers were synthesized from linear polymeric core.[1a,6] Dendronized polymers synthesized from cyclic or branched polymeric core are only few.[7] However, synthesis of these polymers is practically difficult due to the lengthy purification procedure after every stage. So we have tried to synthesize Dendrigraft or Dendronized polymer having branched polymeric core on a solid resin support using Merrifield's solid phase synthesis concept.[8] Thought process behind the synthesis of this supported highly functionalized polymer was that, great amount of functionality would be helpful to achieve sustainable catalysis.

During the last decade, those working with dendrimers have switched their focus from the synthetic attributes to a more applied prominence. Thus, metallodendrimers are gaining attention from a materials science perspective because of their distinctive physical properties, significant structural diversity, leading to promising photophysical and catalytic applications.[9] Several catalytic investigations based on metallodendrimers including those based on polyamidoamine[10] and polypropyleneimine[11] have been reported.[12] Scandium and palladium modified dendritic complexes for Friedel-Crafts reaction[12f] and Suzuki coupling[12g] respectively has been reported recently. Efficiency of these catalysts is overwhelmed due to the cumbersome job of synthesis and purification of the same. Polymer supported synthesis helps to overcome this problem and a number of polymer supported dendritic catalysts were reported.[8a,8g,10d,13] But it was quite surprising that a polymer supported dendrigraft or dendronized polymer was not reported yet. Herein we report copper complexes of dendrigraft polymer having glycerol initiated polyepichlorohydrin as core on an organic polymeric support, Merriield resin, for the synthesis

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Electronic Supplementary Information (ESI) available: [GPC profile, IR, Solid state ^{13}C NMR and EDX spectrum. XRD, XPS, EPR and TG-DTG profile. Bar diagram of reusability of catalyst. Product data of Benzimidazole derivatives]. See DOI: 10.1039/x0xx00000x

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benzimidazole derivatives via the conjugation of o-phenylenediamine with aldehydes or ketones.

Benzimidazole derivatives have been found to possess enormous therapeutic applications including antiviral, antihypertensive, antiulcer, antifungal, antihistaminic, and anticancer activities.[14] For example, the glycinamide-containing benzimidazoles have valuable pharmacological properties such as anti-CCR2 and antithrombotic activities.[15] Several 3-benzimidazol-2-yl-1*H*-quinoxalin-2-ones coordinate with Ru or Os to give the complexes with antiproliferative activity.[16] The discovery of this class of drugs provides an outstanding case history of modern drug development and also points out the unpredictability of pharmacological activity from structural modification of a prototype drug molecule.[17] The imidazole moieties also serve as important intermediates in numerous organic reactions[18] and were used as important ligands for transition metals in various organic transformations.[19] Benzimidazole derivatives have been used in material chemistry also.[20] Due to their wide applications, the preparation of benzimidazole has gained considerable attention in recent years.

However the synthesis of benzimidazole derivatives via the conjugation of o-aromatic diamine with aldehyde and the same with ketone by means of a single catalyst was uncommon. Specifically reported procedures of benzimidazole synthesis exercise the combination of o-aromatic diamine with either aldehyde or ketone. Here we have used our highly functionalized single catalyst for the synthesis of both 2-substituted and 2, 2-disubstituted benzimidazoles.

2. Experimental

2.1 Materials and Methods

Chloromethyl polystyrene (1% DVB crosslinked, 100–200 mesh) was gifted from Thermax India Ltd. as a gift sample. It was washed with methanol, dioxane and acetone and dried under vacuum. Sodium hydride, Tetrabutylammonium bromide, p-toluenesulfonyl chloride, Sodium azide, $LiAlH_4$, methyl acrylate, ethylene diamine, anhydrous copper acetate, o-phenylenediamine, aldehydes and ketones all were purchased from local vendors and were used as received. Absolute ethanol obtained from Sd. fine India Ltd. was used as received. All other solvents were distilled by standard procedures prior to use.

The IR spectra were recorded with samples as KBr pellets using JASCO 4100 FTIR spectrometer. The spectra were recorded at ambient temperature by making pressed pellets of the compounds. Solid state ^{13}C NMR spectra were recorded with a Bruker 400 MHz instrument with a resonance frequency of 75.5 MHz (NCL, Pune). The ^{1}H and ^{13}C NMR spectra of compounds were recorded on a 300 or 400MHz Bruker advanced DPX spectrometer using $CDCl_3$ or DMSO-d_6 as solvent and TMS as an internal standard (NIIST, Trivandrum, STIC, CUSAT). Melting points were determined in an open capillary tube on a Buchi Melting Point B-540 apparatus and are uncorrected. GC analysis was carried out on a 1200 L Single Quadruple, Varian Gas Chromatograph model. The SEM characterization was carried out using the JEOL Model Scanning Electron Micrograph with an attached energy-dispersive X-ray detector. Scanning was done at the 1–20 µm range and images were taken at a magnification of 15–20 kV. Data were obtained using INCA software. The standardization of the data analysis is an integral part of the SEM-EDX instrument employed (STIC, CUSAT). Thermogravimetric analysis was performed using a Perkin Elmer, Diamond TG/DTA system at a heating rate of 10 ^{O}C min^{-1} under an atmosphere of nitrogen using an aluminium pan. Magnetic susceptibilities of the complexes were measured by the Gouy method, using Hg[Co(NCS)] as the calibrant (IIT, Chennai). The copper content was estimated with the help of atomic emission spectroscopy, ICP-AES Thermo Electron IRIS INTREPID IIXSP DUO model. The samples were prepared by first igniting them in a Bunsen flame. Subsequently, the residue was acid digested followed by evaporation to dryness. To the dry mass, 20 mL of distilled water was added and the metal content was estimated in AES. The metal contents were also obtained from EDX analysis. The diffuse reflectance UV-Vis spectra of the solid samples were recorded using UV-Vis-NIR Ocean Optics Spectrophotometer SD 2000 model equipped with a diffuse reflectance accessory. The powder X-ray diffraction (XRD) patterns were recorded on a Bruker AXS. D8 Advance X-ray diffractometer (STIC, CUSAT). XPS measurements were carried out using a multi-probe system (Omicron Nanotechnology, Germany) equipped with a dual Mg/Al X-ray source and a hemispherical analyzer operating at constant analyzer energy (CAE) mode. The Mg Kα X-ray source was operated at 300 W and 15 kV. The base pressure in the analyzing chamber was maintained at 1×10^{-10} mbar. Charging of the samples was corrected by setting the binding energy of the adventitious carbon (C 1s) at 284.6 eV (AIMS, Cochin). EPR analysis was performed using JES– FA200 ESR Spectrometer (IIT, Mumbai). The Merrifield resin supported polymers were synthesized by a reported procedure with minor modification.

2.2 Preparation of polyepichlorohydrin- PECH

Epichlorohydrin (11.742 mL, 0.15 mol) was added through a dropping funnel to a cooled reaction mixture containing dichloromethane (10 mL), Glycerol (0.73 mL, 0.01 mol) and BF_3-etherate (1.256 mL, 0.01 mol) with constant stirring. The reaction mixture was stirred for 24 h at 30 ^{O}C. After completion of the reaction, the reaction mixture was taken in a separating funnel and washed with saturated sodium carbonate solution followed by distilled water. The solvent was removed under vacuum.

Yield: 15 g; Colourless viscous liquid; Mp (GPC): 1589; Polydispersity: 1.06; IR (cm^{-1}); 3490, 2850, 1380, 1100, 750; ^{1}H NMR (400 MHz, $CDCl_3$): 3.2-4.3 (m, CH_2, CH & OH), 2.1 (m, CH, CH_2), 1.78 (m, CH, CH_2), 1.68 (s, OH), 1.15-1.17 (m, CH, CH_2) ppm.

2.3 Coupling of PECH to the Resin

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Sodium hydride (1 g, 0.04 mol) was added to a stirred solution of PECH (5.0 g) in dry DMF (10 mL) at 0 ^{O}C. After 2 h, Merrifield resin (1.0 g), and tetrabutylammonium bromide (216 mg, 0.62 mmol) were added and the mixture was shaken at room temperature (30 ^{O}C) for 20 h. The reaction was quenched by addition of water (20 mL) and the resin was filtered followed by washing with water and dried to constant weight under vacuum to yield the PECH loaded resin. The unreacted PECH was removed by soxhlet extraction with dichloromethane and dried under vacuum for 5 h.

Yield: 4.3 g; Chlorine Capacity: 12.863 mmols/g; Hydroxyl group Capacity: 1.43 mmols/g. IR (cm^{-1}): 3430($\nu_{stretch}$(-OH)), 3056, 2925, 1602, 1535, 1448, 1360, 1107($\nu_{stretch}$(C-O-C)), 695; ^{13}C NMR (75.5 MHz): 19, 38.6, 42.2, 69.9(-CH_2-O-), 130.2, 148.6 ppm.

2.4 Tosylation of hydroxyl group

The Merrifield resin supported PECH (1.0 g) was dispersed in pyridine and cooled to -5 ^{O}C. A cold solution of p-toluenesulfonyl chloride (0.7 g, 0.004 mol) in 5 mL pyridine was added slowly. Upon complete addition, the temperature was held at -5 °C for 30 minute, and allowed to come to room temperature (30 ^{O}C) overnight. The contents of the flask were quenched by pouring ice water. It was filtered and washed with ice water and ethanol. The resin obtained was dried under vacuum for 5 h.

Yield: 1.06 g; % S: 1.63; IR (cm^{-1}); 3054, 2935, 1678, 1528, 1421, 1457, 1260($\nu_{stretch}$(S=O)), 1182($\nu_{stretch}$(S=O)), 1105, 1034, 700; ^{13}C NMR (75.5 MHz): 19, 21(CH_3), 38.6, 42.2, 69.9, 128-130(C_6H_4), 146(C_6H_4) ppm.

2.5 Synthesis of Polyazide

The Merrifield resin supported tosylated PECH (1.0 g) was allowed to swell in 5 ml DMF, sodium azide (0.455 g, 0.007 mol) in 5ml DMF was added and heated at 85-90 ^{O}C for 24 h. After the reaction, it was filtered and washed with water. The resin obtained was dried under vacuum for 5 h.

Yield: 1.34 g; IR (cm^{-1}); 3050, 2850, 2100($\nu_{stretch}$(N_3)), 1600, 1474, 1120, 1025; ^{13}C NMR (75.5 MHz,): 19, 20.8, 42.3, 49(-CH_2-N_3), 70.0, 125.8, 133.6, 148.2 ppm.

2.6 Synthesis of Polyamine (Synthesis of G0 polymer)

The Merrifield resin supported polyazide (1 g) was suspended in dry THF taken in a RB flask and kept at 0 ^{O}C in an ice bath. Slurry of $LiAlH_4$ (0.304 g, 0.008 mol) in dry THF was added drop wise to the reaction mixture with stirring. The reaction mixture was kept at 0 ^{O}C for 1h. The temperature was slowly brought to 50 ^{O}C. It was stirred at 50 ^{O}C for two days to ensure complete reduction. Excess $LiAlH_4$ was removed by adding ethyl acetate. It was filtered and washed with water. The resin was dried under vacuum for 5 h.

Yield: 0.83 g; Amine Capacity: 13.45 mmols/g. IR (cm^{-1}); 3477($\nu_{stretch}$(NH)), 1568(ν_{bend}(NH)), 1340, 1047; ^{13}C NMR (75.5 MHz,): 18.2, 20.8, 42(-CH_2NH_2), 71, 125.8, 133, 147.3 ppm.

2.7 Michael addition reaction (Synthesis of G 0.5 polymer)

The Merrifield resin supported G0 polyamine (0.5 g) was added in portions to a RB flask containing methyl acrylate (0.68 mol, 8 mL) and methanol (5 mL) at room temperature (30 ^{O}C) with stirring. The reaction mixture was stirred at room temperature for 7 days under an atmosphere of nitrogen. The reaction was monitored using Kaiser Ninhydrin test. After the reaction, excess methyl acrylate was decanted; the solution was filtered and washed and water. It was dried under vacuum for 5 h.

Yield: 3.2 g; IR (cm^{-1}): 3426, 2912, 1741($\nu_{stretch}$(COO)), 1310, 1265, 1056; ^{13}C NMR (75.5 MHz); 20, 45, 65, 125, 144, 169.8(COO) ppm.

2.8 Procedure for transamination (Synthesis of G1 polymer)

The Merrifield resin supported G0.5 polymer (1.0 g) was added in small portions with stirring to a mixture of ethylene diamine (0.135 mol, 10 mL) and methanol (10 mL) taken in a RB flask and cooled to 0 ^{O}C in an ice salt bath. The reaction mixture was stirred at 0 ^{O}C for 1h and the temperature was allowed to rise to the room temperature (30 ^{O}C) and stirred at room temperature for 7 days to ensure complete reaction. After the completion of the reaction, the resin was filtered and washed with water. It was dried under vacuum for 5 h.

Yield: 1.7 g; Amine Capacity: 22.13 mmols/g; IR (cm^{-1}): 3477, 2935, 1655($\nu_{stretch}$(CONH)), 1375, 1056; ^{13}C NMR (75.5 MHz); 20, 45, 65, 125, 144, 167.4(CONH) ppm.

2.9 Michael addition reaction (Synthesis of G1.5 polymer)

The Merrifield resin supported G1 polymer (1.0 g) was added in portions to a RB flask containing methyl acrylate (0.27 mol, 25 mL) and methanol (30 mL) at room temperature (30 ^{O}C) with stirring. The reaction mixture was stirred at 30 ^{O}C for 10 days under an atmosphere of nitrogen to ensure complete reaction. The reaction was monitored using Kaiser Ninhydrin test. After the reaction, excess methyl acrylate was decanted; the solution was filtered and washed with water. It was dried under vacuum for 5 h.

Yield: 3.34 g; IR (cm^{-1}): 3475, 2984, 1747($\nu_{stretch}$(COO)), 1376, 1056; ^{13}C NMR (75.5 MHz); 20, 45, 65, 125, 144, 167.3(CONH), 169.7(COO) ppm.

2.10 Procedure for transamination (Synthesis of G2 polymer)

The Merrifield resin supported G1.5 polymer (1.0 g) was added in small portions with stirring to a mixture of ethylene diamine (0.27 mol, 20 mL) and methanol (20 mL) taken in a RB flask and cooled to 0 ^{O}C in an ice salt bath. The reaction mixture was stirred at 0 ^{O}C for 1h and the temperature was

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allowed to rise to room temperature (30 ^{O}C) and stirred at room temperature for 7 days to ensure complete reaction. After the completion of the reaction, the resin beads were filtered and washed with water. It was dried under vacuum for 5 h.

Yield: 1.8 g; Amine Capacity: 30.24 mmols/g; IR (cm^{-1}): 3473, 2958, 1645($\nu_{stretch}$(CONH)), 1375, 1041; ^{13}C NMR (75.5 MHz); 20, 48, 65, 125, 144, 167.1(CONH), 167.4(CONH) ppm.

2.11 Synthesis of copper complex of dendrigraft GLR-G2 polymer having glycerol initiated polyepichlorohydrin as core

A 50 mL round bottom flask was charged with 250 mg of Merrifield resin supported GLR-Gn (n= 0, 1 and 2) polymer having "*x*" mmols of amine capacity. It was allowed to swell in 5 ml DMF for 2 h. Quantitative amount corresponding to "*x*" mmols of anhydrous copper acetate in 10 mL methanol was added to the reaction flask. The reaction mixture was stirred at 50 ^{O}C for two days (48 h). The polymer was filtered and washed with water. The filtrate and washings were collected together and concentrated. This concentrated solution was used for the estimation of metal ions by standard methods. The polymer-supported metal complex was dried under vacuum for 5 h.

2.12 General procedure for the synthesis of benzimidazole derivatives from aldehydes /ketones

A 25 mL RB flask having side inlet was charged with o-Phenylenediamine (1.0 mmol), aldehyde / ketone (1.0 / 1.2 mmol), ethanol (3.0 mL) and catalyst GLR-G2-Cu (0.007 mol %, 10mg). The mixture was stirred at room temperature (30 ^{O}C) under air. After the reaction was completed (TLC and GCMS determination), the resulting solution was filtered, washed with ethyl acetate, concentrated by a rotary evaporator, and the residue was purified by column chromatography on silica gel using the eluent hexane and ethyl acetate (9:1) to provide the desired target product.

2.13 Test for Catalyst Heterogeneity

To confirm whether the conjugation reactions occurred *via* a heterogeneous catalytic process, and to find out any leaching of the metal complex from the polymer-bound dendrigraft catalyst into the reaction medium during the synthesis of benzimidazole derivatives, reactions were conducted according to above mentioned procedure. After completion of the reaction, the catalyst was filtered and the filtrate obtained was extracted with ethyl acetate and water. The aqueous layer was subsequently treated with another set of reactants and the reactions were allowed to continue for speculated time. There was no formation of the product. This suggests that the reaction does not proceed after removal of the catalyst. Also, the presence of copper could not be detected when the filtrate, obtained after separating the solid catalysts by filtration, was subjected to ICP-AES analysis. These facts ruled out the possibility of the copper species leaching out of the catalyst that proves the heterogeneous nature of the catalytic process.

2.14 Regeneration and Recycling of the Catalyst

The reusability of the catalyst for subsequent catalytic cycles was examined using cyclohexanone / benzaldehyde and o-phenylenediamine as the substrate. In the oxidative cyclisation reaction, after the completion of the reaction, the solid catalyst was separated from the reaction mixture by filtration, washed with ethyl acetate and was dried under vacuum for about 5h. The dried solid catalyst was weighed and added to a fresh reaction mixture of cyclohexanone (1.2 mmol) / benzaldehyde (1.0 mmol), and o-phenylenediamine (1.0 mmol) and ethanol (3 mL). The progress of the reaction was monitored by thin layer chromatography (TLC) and GCMS. The procedure for the above mentioned system was repeated for five reaction cycles.

3. Results and discussion

The Merrifield resin supported dendrigraft amidoamine polymer was synthesized using the schematic procedure (Scheme 1). The branched hydroxyl terminated polyepichlorohydrin (PECH) was prepared by the ring opening polymerization of the oxirane group in epichlorohydrin (ECH) in the presence of glycerol by activated monomer mechanism (AMM).[21] It was a colorless viscous liquid. From GPC, the molecular weight of PECH was found to be 1589 with a polydispersity of 1.06. The PECH was coupled to the resin via sodium hydride and tetrabutylammonium bromide.[22] After coupling, quantitative estimation shows the amount of chlorine as 12.863 mmols g^{-1}. The EDX spectrum shows carbon, oxygen and chlorine as the main constituents of the polymer (ESI). The ^{13}C NMR spectrum of PECH loaded Merrifield resin shows broad peak around 69.9 ppm (Figure 1). Also the peak indicating the hydroxyl group after the loading of PECH to Merrifield resin can be observed at 3430 cm^{-1} in the IR spectrum (ESI).

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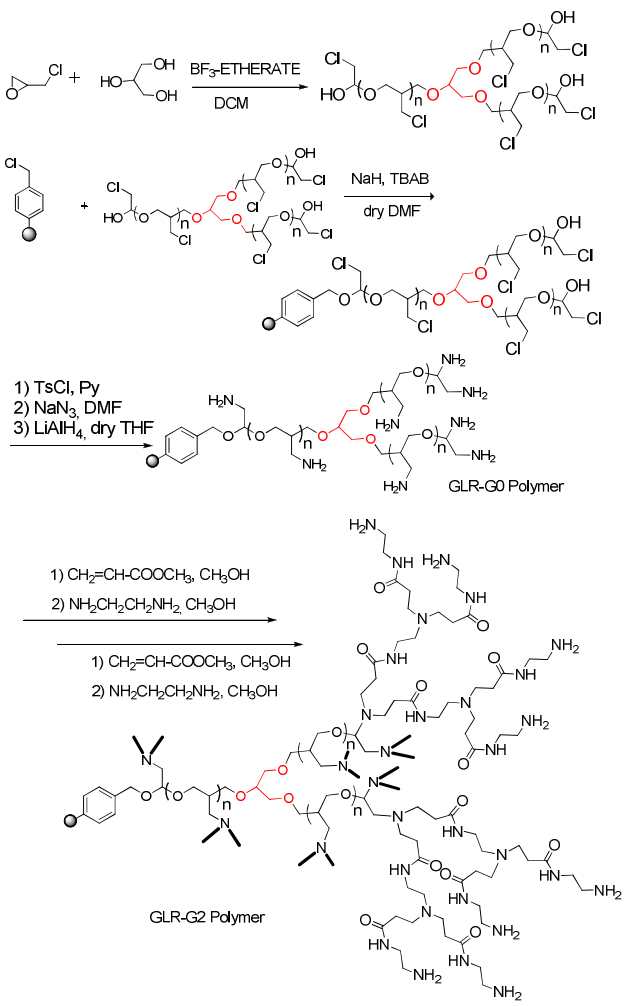

Scheme 1 Synthesis of GLR-G2 Dendrigraft Polymer

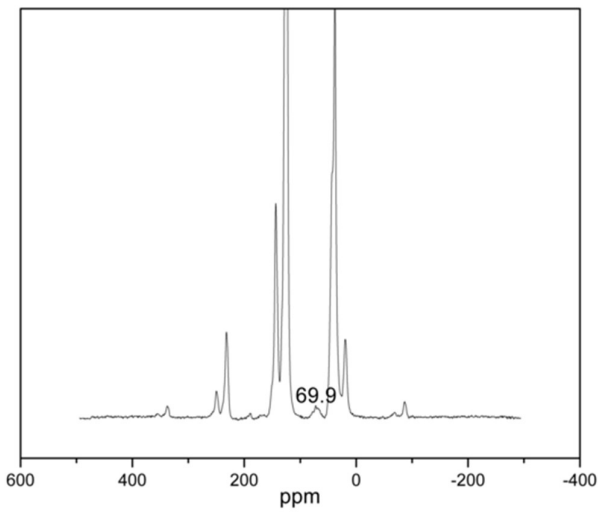

Figure 1 Solid state ^{13}C NMR spectrum of PECH loaded Merrifield resin

The hydroxyl groups of PECH loaded resin was estimated quantitatively and was found to be 1.43 mmol g^{-1} of the polymer. However, the hydroxyl groups of the polymer were to be protected in order to avoid unwanted reactions and to promote dendron growth. This problem can be managed by producing glycidyl azide polymer without terminal hydroxyl groups. This polymer is produced by reacting supported polyepichlorohydrin with p-toluenesulfonyl chloride (TsCl) in pyridine, and reacting the resulting tosylated polyepichlorohydrin with sodium azide in dimethylformamide.[23] After tosylation, percentage of sulphur was found to be 1.63% from CHNS data. Thus azidation of tosylated PECH with sodium azide yields quantitatively the corresponding azide polymer.[23-24] An intense band at 2100 cm^{-1} in the IR spectrum confirms the presence of azide functionality (ESI). The colour of the resin was changed from off-white to brown. The polymeric diazide on reduction with lithium aluminium hydride ($LiAlH_4$) in dry THF got converted to the polyamine (GLR-G0).[11f,22a] The band at 2100 cm^{-1} in the IR spectrum disappeared and a band at 3477 cm^{-1} showed the presence of amine functionality. The positive Kaiser-ninhydrin test confirmed the reduction of polyazide to polyamine. The quantitative estimation showed the presence of 13.45 mmols of amine per gram of the resin. In the ^{13}C NMR spectrum of tosylated PECH, polyazide and G0 polyamine, no characteristic peak can be observed since the peaks due to the tosyl carbon, $-CH_2N_3$ and $-CH_2NH_2$ get merged within the region of Merrifield resin. In the TG-DTG curve of GLR-G0 polymer, the first mass loss of about 25% around 100-300 ^{O}C was due to the elimination of amine as molecular nitrogen. The second mass loss of about 36% at 382 ^{O}C was due to the degradation of resin loaded polyether.[25] (Figure 2). This information was obtained in comparison with the TG of PECH loaded resin (ESI).

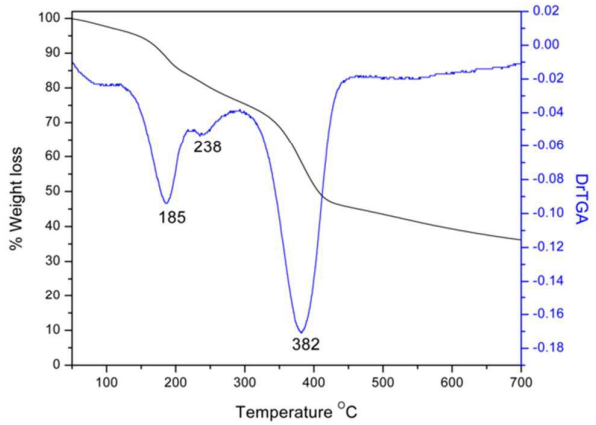

Figure 2 TG-DTG Profile of GLR-G0 Polymer

Michael addition of the GLR-G0 polyamine having amino terminal with methyl acrylate resulted in GLR-G0.5 polymer having ester terminal.[26] As a result of this reaction a peak at

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1741 cm^{-1} due to ester carbonyl can be observed in the IR spectrum (ESI). The signal corresponding to 169.8 ppm in the ^{13}C NMR spectrum of GLR-G0.5 is due to carbonyl carbon of ester functionality (Figure 3). The above polymer was coupled with ethylene diamine to achieve a new amino terminated resin.[26] The amidoamine G1 polymer (GLR-G1) shows bands at 1655 cm^{-1} and 3482 cm^{-1} in the IR spectrum attributable to the carbonyl and amine moiety of the polymer respectively (ESI). The quantitative estimation showed the presence of 22.13 mmols of amine per gram of the resin. In the ^{13}C NMR spectrum, the peak corresponding to 167.4 ppm corresponds to carbonyl carbon of amide functionality (ESI).

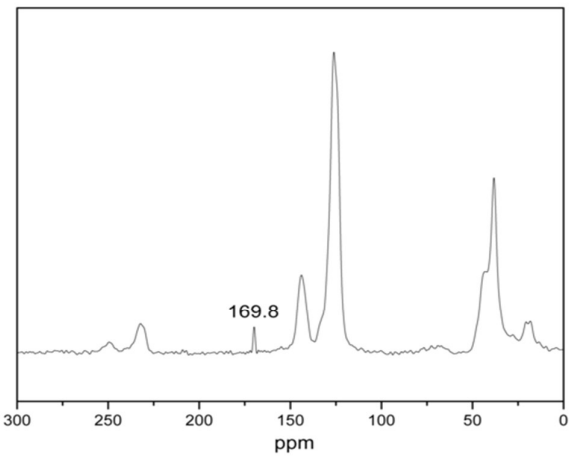

Figure 3 Solid state ^{13}C NMR spectrum of G0.5 dendrigraft polymer

In the TG curve of GLR-G1 resin; two mass loss steps were observed. The first decomposition corresponded to nearly 30% mass loss in the temperature around 212.97 ^{O}C. The second stage mass loss of 40% was observed around 410 ^{O}C (Figure 4). The synthesis procedure was repeated to get GLR-G2 Dendrigraft polymer.[26] Upon subsequent Michael addition of the GLR-G1 polyamine with methyl acrylate, showed a peak at 1747 cm^{-1} in the IR spectrum (ESI). In the ^{13}C NMR spectrum of GLR-G1.5, the signal corresponding to 169.7 ppm and 167.3 ppm are due to carbonyl carbon of ester and amide functionality respectively (ESI). Similarly, subsequent amide coupling with ethylene diamine gives the amidoamine G2 polymer (GLR-G2). The peaks at 1645 cm^{-1} and 3482 cm^{-1} in the IR spectrum of G2 polymer are due to carbonyl and amine moiety of the polymer respectively (ESI).

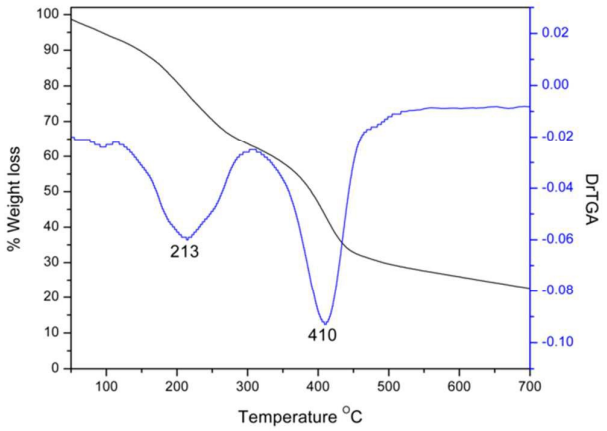

Figure 4 TG-DTG Profile of GLR-G1 Polymer

The signals at 167.1 ppm and 167.4 ppm in the ^{13}C NMR spectrum of GLR-G2 polymer was attributed to carbonyl carbon of different amide functionality (ESI). The quantitative estimation of amine functionality in GLR-G2 polymer was found to be 30.24 $mmolg^{-1}$, greater than the amine content of GLR-G1 polymer which was again greater than that of GLR-G0 polymer that signifies the amount of growth on to the polyether backbone. TG curve of GLR-G2 polymer shows similar decomposition pathway as that of GLR-G1 polymer, but exhibited a mass loss of 42% between 120-320 ^{O}C and 45% at 416 ^{O}C (Figure 5). Thus the % weight loss has increased in the TG profile from G0 to G2 supported the generation growth of the dendrons.

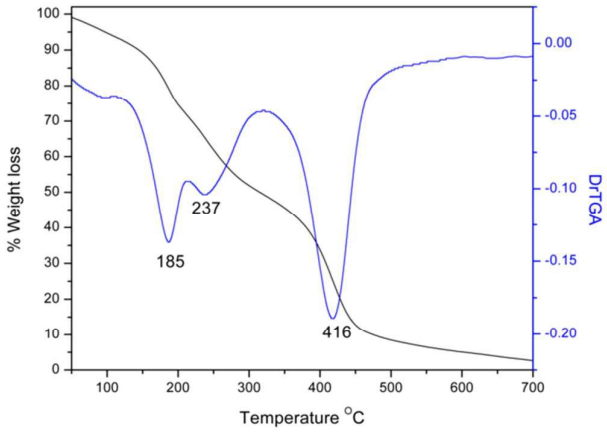

Figure5 TG-DTG Profile of GLR-G2 Polymer

Copper complexes are well known for their catalytic activity. Recently, copper and other metal complexes of dendritic and nondendritic polymer as catalyst for organic reactions have been developed from this laboratory.[10d,13a,27] In the present work, we have tried to develop copper complexes

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of dendrigraft polymer having glycerol initiated polyepichlorohydrin as core, GLR-G2-Cu (Figure 6) in order to effectively catalyze different organic reactions in an environmentally benign manner. Chloromethylated polystyrene crosslinked with 1% DVB was used as the support mainly owing to its superior flexibility, which was known to facilitate the grafting of metal ions via dendritic ligands.[28] The copper complex of each of the GLR-Gn (n= 0, 1 and 2) polymer was synthesized by adopting the schematic procedure (Scheme 2). For the complexation of dendrigraft polymer with copper, the copper salt and solvent was optimized. It was found that copper acetate in methanol at a temperature of 50 ^{O}C was found to be the best condition for the complexation of copper with GLR-Gn (n= 0, 1 and 2) dendritic polymer. Factors such as the maintenance of the required contact time and temperature were also found to be important for the desired synthesis. The effort to increase the loading by increasing the contact time to 2 days and temperature of about 50 ^{O}C was successful. The copper coordinated dendritic polymer appeared as dark green powder. It is worth mentioning that all the catalysts G0, G1 and G2 were highly functionalized, non-hygroscopic, and stable and can be stored for a prolonged period of time without any change in its catalytic efficiency.

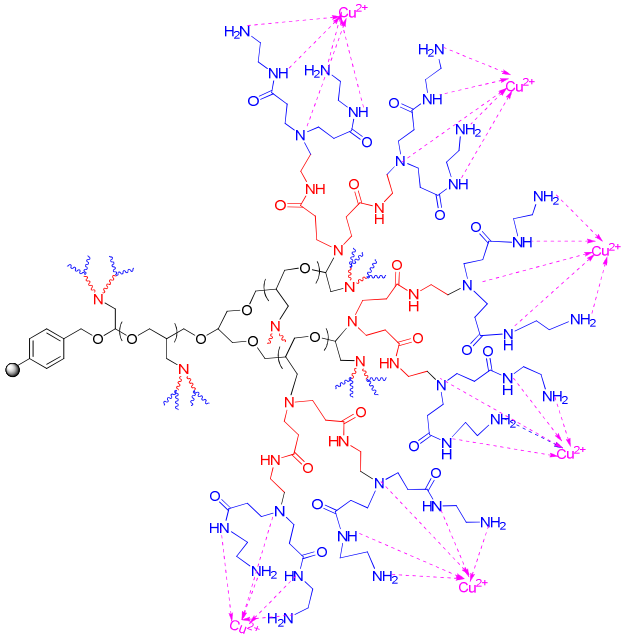
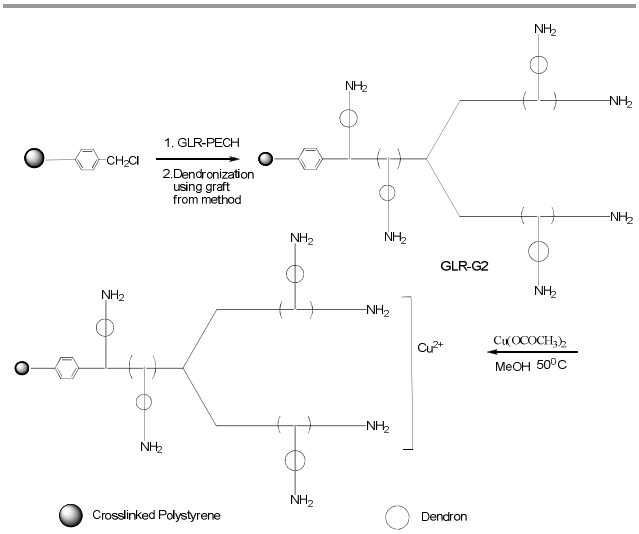


Figure 6 Merrifield resin supported dendrigraft GLR-G2-Cu polymer having glycerol initiated PECH as core



Scheme 2 Synthesis of Merrifield resin supported dendrigraft GLR-G2-Cu polymer having glycerol initiated PECH as core.

3.1 Catalyst Characterization

The synthesized catalyst was characterized with different techniques which are discussed.

3.1.1 ICP-AES Analysis

The copper loading for GLR-G0-Cu, GLR-G1-Cu and GLR-G2-Cu, based on ICP-AES analysis and confirmed by EDX analysis, were found to be 16.20, 28.40 and 44.39% of the polymer, respectively and the results are given in Table. 1. It is therefore assumed that average of 2.16 peripheral amine ligands was bound to each Cu moieties in GLR-G2-Cu complex. The peak for ester was not present in the IR spectrum indicating that acetate ion was not included in the co-ordination sphere. The room temperature magnetic moments of the copper (II) complexes fall in the range 1.9 - 2.0 B.M [GLR-G0-Cu: 1.95, GLR-G1-Cu: 1.97 and GLR-G2-Cu: 2.01], which are very close to the spin only value for d^9. The Cu complexes were paramagnetic in nature, as was evident from the magnetic susceptibility measurements, which was consistent with the presence of Cu centers in their +2 oxidation state.

3.1.2 SEM & Energy Dispersive X-ray (EDX) Analysis

The morphological changes taking place on the surface of the Merrifield resin, as a result of grafting of the polyamidoamine with glycerol initiated polyepichlorohydrin as core and the subsequent loading of copper ions, was examined by employing scanning electron microscopy. The micrographs of dendrigraft polyamine revealed that the smooth and flat surface of the starting Merrifield resin got disrupted and became crushed into powder, which, then aggregated into small units. But after complexation with copper, the polymer showed metallic lustre (Figure 7a & 7b). Even though, the SEM micrographs show randomly oriented aggregates, after

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complexation with copper, each aggregate became more compact.

Table. 1 Analytical data for GLR-Gn and GLR-Gn-Cu

Polymer	Amine capacity (mmols/g)[a]	Copper loading (%) (ICP-AES)	Copper loading (mmols/g)	Copper loading (%) (EDX)
GLR-G0-(Cu)	13.45	16.20	2.55	15.94
GLR-G1-(Cu)	22.13	28.40	4.47	28.23
GLR-G2-(Cu)	30.24	44.39	6.99	43.27

[a] Amine capacity before complexation with Copper

Energy dispersive X-ray spectroscopic (EDX) analysis, which provides in situ chemical analysis of the bulk, was carried out focusing multiple regions over the surface of the polymer. EDX spectra clearly showed Cu, C, N and O as the constituents of the catalyst (ESI). The results presented in Table 1 are the average of the data from the different regions. The data obtained on the composition of the compounds from the energy dispersive X-ray spectroscopy, were consistent with the elemental analysis values (Table 1).

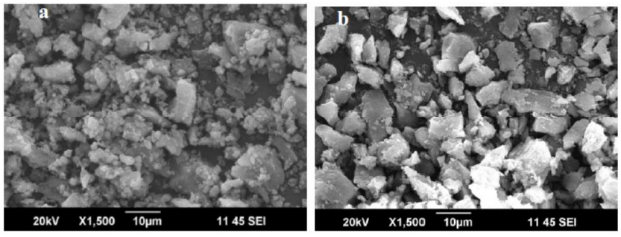

Figure 7 Scanning electron micrographs of (a) GLR-G2 and (b) GLR-G2-Cu

3.1.3 IR Spectral Studies

The IR spectra showed small characteristic differences between the spectral pattern originating from the dendrigraft–copper complexes (GLR-G2-Cu) and the spectra of the dendrigraft amine polymer (GLR-G2) (ESI). The significant features of IR spectra are summarized in Table 2. The broadness of the band due to stretching of amine was observed to be reduced to a small extent in the spectrum of the copper complex suggesting coordination of Cu by the dendritic amine ligands. Apart from the typical absorptions at ~3456 (ν_{sym}(NH)), 2928 ($\nu_{aliphatic}$(CH)), 1633 ($\nu_{secondary\ amide}$(CO)), 1565 (ν_{bend}(NH)), 1410 (ν_{bend}(C-O-H)), 1015 ($\nu_{CN\ sym}$(C-NH)) and 700 cm^{-1} ($\nu_{NH\ wag}$(CH-NH)), the spectra of GLR-G2-Cu showed a shoulder band at ~467 cm^{-1} which is attributable to ν_{sym}(Cu-N), giving clear indication of complexation of copper moiety to dendritic polymeric matrix.[29] Upon complexation of Cu ions in the dendritic GLR-G2 resins, the spectra of GLR-G2 exhibited a distinct shift of ν_{sym}(NH) and ν_{sym}(NHCO) to a lower frequency (Table 2), compared to the uncomplexed polymer, along with some sharpening of bands. The position of the ν_{sym}(NH) absorption in the polymeric complexes was altered only to a small extent compared to uncomplexed dendritic matrix. It is therefore inferred that all the amino groups have not participated in co-ordination, nevertheless gives clear indication of binding of copper to both amide and amine nitrogen. The presence of polymer bound copper in GLR-G2-Cu, has been confirmed from the occurrence of typical ν_{sym}(Cu–N) vibration modes at ~467 cm^{-1}. The prominent absorption at ~725 cm^{-1} has been narrowed and shifted towards lower frequency region at *ca*. 700 cm^{-1} assigned to ν_{wag}(N-H) of primary or secondary amines.

Table 2 Infrared (IR) spectral data for GLR-G2 and GLR-G2-Cu

Polymer	ν_{sym} (NH)	ν_{bend} (NH)	ν_{sym} (NHCO)	ν_{bend} (C-OH)	ν_{sym} (C-N)	ν_{sym} (Cu-N)	ν_{wag} (NH)
GLR-G2	3469	1562, 1565	1644	1374	1003	-	725
GLR-G2-Cu	3456	1565	1633	1410	1015 950	467	700

3.1.4 EPR Spectral Studies

EPR Spectral studies of GLR-G2-Cu show typical axial spectra with four hyperfine lines, which are characteristic of monomeric copper (II) complexes. The g and *A* values are obtained from the simulated spectrum (ESI) given in Table 3. In the present case, g_{II} is found to be greater than $g_{\perp}$. This predicts a square pyramidal geometry to five coordinated complex rather than a trigonal bipyramidal structure which would be expected to have $g_{\perp}$ greater than g_{II}.[30]

Table 3 Splitting parameters g and A from EPR spectra

Polymer	g_{II}	$g_{\perp}$	g_{av}	A_{II}	$A_{\perp}$	A_{av}
GLR-G2-Cu	2.25	2.05	2.11	175.2	13.81	64.73

I.A. Gentle et al., studied the EXAFS data for copper(II)-PAMAM solutions and the data were fitted with acceptable parameters using a model in which primary amine, amide and tertiary amine nitrogen atoms were involved in bonding with the copper (II) ion to form five- and six membered rings.[9a,31] Thus GLR-G2-Cu comprises of coordination of copper to two amine nitrogens, two amide nitrogens and one tertiary nitrogen of amidoamine unit.

3.1.5 Electronic Spectral Studies (UV-Vis DRS)

Organic ligands upon complexation with transition metal ions, due to interaction with the metal ion, show notable changes in the electronic properties of the system. New features or bands in the visible region due to d-d absorption and charge transfer spectra from metal to ligand (M→L) or ligand to metal (L→M)

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can be observed and this data can be processed to get information regarding the structure and geometry of the compounds. R. M. Crooks et al., examined complexation between PAMAM dendrimers and Cu^{2+} in aqueous solution using UV-Vis spectroscopy.[9b] In the absence of G_4-OH, Cu^{2+} exists primarily as $[Cu\text{-}(H_2O)_6]^{2+}$. This complex gives rise to a broad, weak absorption band centered at 810 nm, which arises from the d-d transition of Cu^{2+} in a tetragonally distorted octahedral or square-planar H_2O-ligand field. In the presence of 0.05 mM hydroxyl terminated PAMAM dendrimers (Gn-OH, n = 2, 3, and 4), λ_{max} for the d-d transition was shifted to 605 nm.

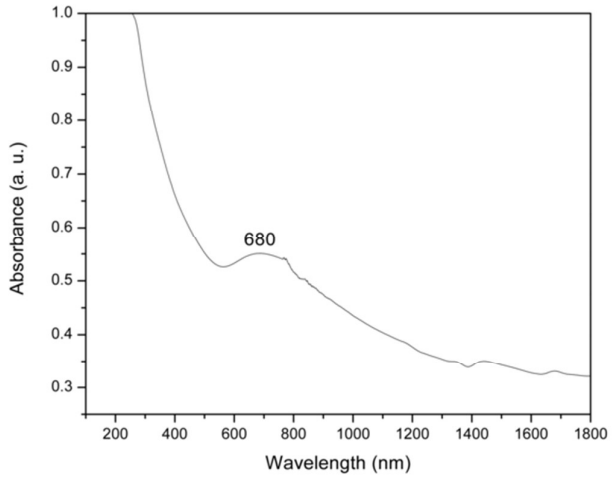

Figure 8 UV-Vis-DRS spectrum of GLR-G2-Cu

In accordance with this, the diffuse reflectance UV-Vis spectra of GLR-G2-Cu (Figure 8) displayed a broad peak in the region of 580–780 nm with maximum intensity at 680 nm which is characteristic of five coordinated copper complexes having square pyramidal geometry. The peak may be ascribed to the absorption due to overlapping of allowed d-d transitions in copper after coordination with dendritic ligands.

3.1.6 X-ray Diffraction Studies

The room-temperature X-ray diffraction patterns of the dendrigraft polymer, GLR-G2 and the Copper complexed dendrigraft polymer, GLR-G2-Cu on Merrifield resin are overlayed (ESI). The GLR-G2 sample displayed diffraction peaks at 2ϑ values of 15.0, 20.0, 23.0, 31.3, 35.0, 40.0, 54.0 and 62.8°. These values are close to the ones observed for the GLR-G2-Cu, which were ascribed to the (200), (311), (100), (110), (440), (111), (311) and (303) planes, respectively. After complexation with copper, the diffraction peaks at 2ϑ value of 47.0°, 35.0° and 23.0° corresponding to (220), (440) and (100) got disappeared or decreased in intensity while a broad, weak peak at 60° corresponding to (222) plane appeared indicating a mixed behaviour of crystalline and amorphous nature.

3.1.7 X-ray Photoelectron Spectroscopy

XPS is an efficient technique for studying the electronic behaviour of the species formed on the surface. Figure 9 presents the deconvoluted Cu (2p) XPS spectra of the polymer anchored Cu complex.

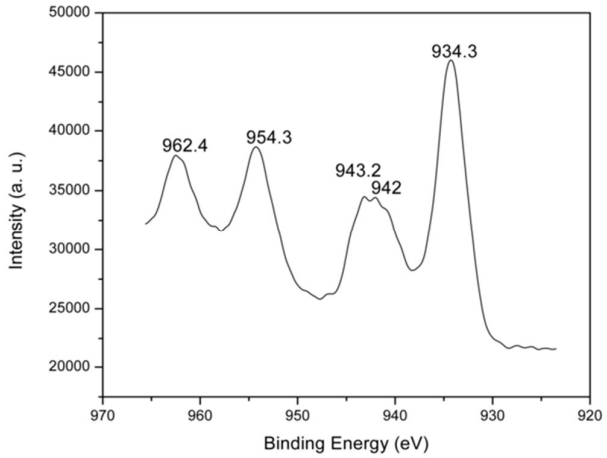

Figure 9 XPS deconvoluted spectra of Cu ($2p_{3/2}$) of GLR-G2-Cu

The catalyst displayed characteristic Cu $2p_{3/2}$ singlet with peak located at 934.3 eV. Strong satellite peaks were observed at 942, 943.2, 954.3 and 962.4 eV. The binding energy values observed are in good agreement with the available literature data for Cu ions in the +2 oxidation state.[32] The presence of Cu (II) in supported dendritic compound has thus been confirmed from the results of XPS analysis. The XPS results are also consistent with the paramagnetic nature of the catalysts, as evidenced by the magnetic susceptibility measurements.

3.1.8 TG-DTG Analysis

Evaluation of the thermogravimetric data of the GLR-G2 functionalized resins and the corresponding Cu loaded dendrigraft polymer was performed. Considerable extent of decomposition was observed in the thermogram of both GLR-G2 (Figure 5) and GLR-G2-Cu (Figure 10) at the temperature 416.0 and 406.65 ^{O}C respectively owing to the degradation of the polymeric backbone. This occurs as a common feature of the polystyrene species.[25a,33] In GLR-G2-Cu polymer, the first step of the decomposition is attributable to the loss of non-coordinated water, occurring in the temperature range of 65-105 ^{O}C. Apart from this, in the case of GLR-G2-Cu, a decomposition step with a weight loss of 35% occurs in the temperature range of 130–300 ^{O}C. By analogy with the thermal decomposition characteristics of GLR-G2 undergoing decomposition with a weight loss of 42% occurring in the temperature range of 120-320 ^{O}C, it is revealed that, copper ions are bound quantitatively to the polymer matrix. From the reports regarding polyazides,[34] polyethers[25b] and polystyrenes[25a,33], the decompositions may be ascribed to the release of amines as nitrogen and hydrogen, carbonyls as CO or CO_2 and the degradation of the polymeric backbone to be

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left with a residue containing copper oxide. The TG-DTG analysis data for the compounds are thus in agreement with their incorporation and percentage composition.

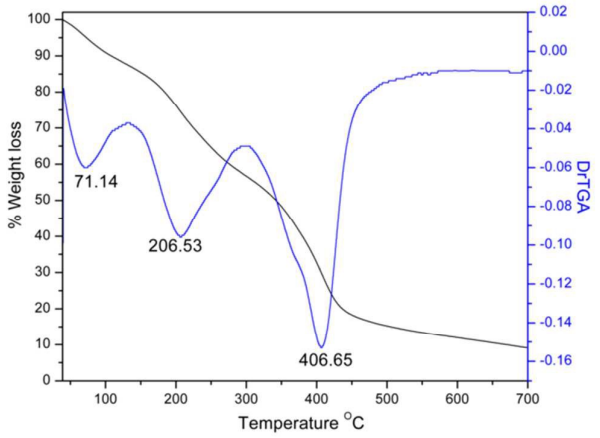


Figure 10 TG-DTG profile of GLR-G2-Cu

3.2 Catalytic Activity of Resin Supported Dendrigraft GLR-Gn-Cu Complex

3.2.1 Synthesis of Benzimidazole Derivatives

The wide-spread interest in benzimidazole containing structures has prompted extensive studies for their synthesis. There are two general methods for the synthesis of 2-substituted benzimidazoles. One is the coupling of o-phenylenediamines and carboxylic acids[35] or their derivatives which often require strong acidic conditions,[36] and sometimes combines with very high temperatures or the use of microwave irradiation.[37] The other way involves a two-step procedure that includes the oxidative cyclo-dehydrogenation of aniline Schiff's bases, which are often generated in situ from the condensation of o-phenylenediamines and aldehydes. In the latter reaction, various oxidants have been used.[20,38] A number of catalysts were developed for the synthesis of benzimidazole derivatives from o-phenylenediamine and especially aldehydes.[20f,39]

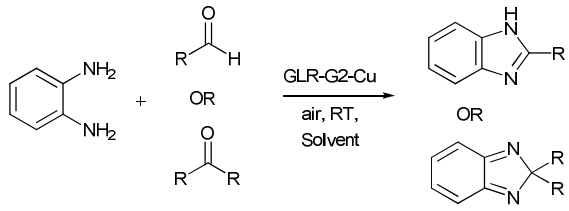
Table 4 Comparison of Catalytic performance[a]

Catalyst	Time	Temperature	Yield (%)[b]
K10TiClay[27a]	2h	120 °C	79
INDION-190[42a]	4h	70 °C	89
CAN[42b]	2h	50 °C	98
Ti(IV)isopropoxide[42c]	2h	100 °C	92
Glycerol-H_2O[42d]	2h	90 °C	75
Thiamine hydrochloride[39a]	1.5h	RT	93
CoO(II)[42e]	6h	RT	93
$Co(OH)_2$[42e]	4h	RT	96
$FeCl_3$/PANI[42f]	30min	RT	90

[a]Reported catalysts require high temperature conditions or long reaction time or not reusable. [b]Yield with respect to benzaldehyde.

Recently, copper catalyzed reactions with inexpensive and less toxic copper-catalysts[40] and molecular oxygen have shown wide application with high tolerance of functional groups in benzimidazole synthesis.[41] Most of the reported catalysts were homogeneous, even though, they applied green chemistry principles or the reported heterogeneous catalysts used high temperature or oxidants other than molecular oxygen. A comparison of different catalysts used for the reaction with similar substrates is shown in Table 4. So we have tried to combine the benefits of both heterogeneous and dendritic behaviour to address the above mentioned issues.

In a survey of catalytic activity, dendrigraft GLR-Gn (n= 0, 1 and 2) copper complexes were employed in the synthesis of benzimidazole derivatives. A variety of benzimidazole derivatives have been synthesized in excellent yields from aromatic aldehyde and aliphatic or cyclic ketones (Scheme 3). In order to optimize the reaction conditions, the effect of various reaction parameters, such as type of solvent, reaction temperature, substrate ratio, catalyst concentration, etc., were evaluated by using benzaldehyde / cyclohexanone and o-phenylenediamine as model substrates and GLR-G2-Cu as the catalyst. The emphasis in the present work has been to conduct the reactions using environmentally safe solvents including water and to avoid the use of chlorinated solvents. Nevertheless, apart from water, methanol, ethanol, acetonitrile and DMF we have screened the reaction in dichloromethane as well.



Scheme 3 Synthesis of benzimidazole derivatives.

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The nature of solvent was observed to have a substantial effect on the activity of the catalyst and the product selectivity of the reaction. The reactions were performed at ambient temperature under magnetic stirring. From the results presented in Table 5 it is evident that the reaction conducted in the molar ratio of *o*-phenylenediamine : cyclohexanone / benzaldehyde of 1.0 : 1.2 / 1.0 in ethanol at room temperature proceeded smoothly to selectively yield the corresponding 2,2-disubstituted or 2-substituted benzimidazole as the exclusive product.

Table 5 Optimization of solvent[a]

Solvent	Yield (%)[b]	Yield (%)[c]
DMF	22	20
CH_3CN	35	23
Dichloromethane	14	12
Ethanol	96	94
Methanol	90	89
Water	74	72

[a] Reaction conditions: o-phenylenediamine (1.0 mmol), cyclohexanone (1.2 mmol), benzaldehyde (1.0 mmol), catalyst-20 mg, Room temperature (30 ^{O}C), air, [b] Isolated Yield using cyclohexanone and [c] Isolated Yield using benzaldehyde.

Increasing the catalyst amount reduces the reaction time from 80 min (with 0.004 mol% catalyst) to 30 min and 60 min (with 0.007 mol% catalyst) for cyclohexanone and benzaldehyde respectively (Table 6). Even though, 0.014 mol% catalyst takes only 40 minute for the completion of the reaction in the case of benzaldehyde, we preferred 0.007 mol% as the optimum catalyst amount. Also water as solvent gave 74% and 72% yield for substrates cyclohexanone and benzaldehyde respectively, good solvent ethanol, was found to be the solvent of choice.

Table 6 Optimization of amount of catalyst[a]

Amount of catalyst (mg)	Amount of catalyst (mol%)	Time (min)[b]	Yield (%)[c]	Time (min)[d]	Yield (%)[e]
5	0.004	80	90	80	87
10	0.007	30	96	60	94
15	0.011	30	96	50	94
20	0.014	30	96	40	94
25	0.018	-	-	40	94
30	0.021	-	-	40	94

[a] Reaction conditions: o-phenylenediamine (1.0 mmol), cyclohexanone (1.2 mmol), benzaldehyde (1.0 mmol), Ethanol-3ml, Room temperature (30 ^{O}C), air, [b] time and [c] isolated yield using cyclohexanone, [d] time and [e] isolated yield using benzaldehyde.

Further, we have studied the generation effect on benzimidazole derivative synthesis with benzaldehyde / cyclohexanone as substrate using 0.007 mol% catalyst (Table 7). In both the cases, G0, G1 and G2 dendrigraft copper catalyst showed good to excellent product yield. Therefore all generations (GLR-Gn-Cu, n= 0, 1 and 2) including the low generation GLR-G0-Cu were active catalysts towards the synthesis of benzimidazole derivatives. The negative dendritic effect was not pronounced here and the usual concept of slow reaction of supported catalysts was also not observed.

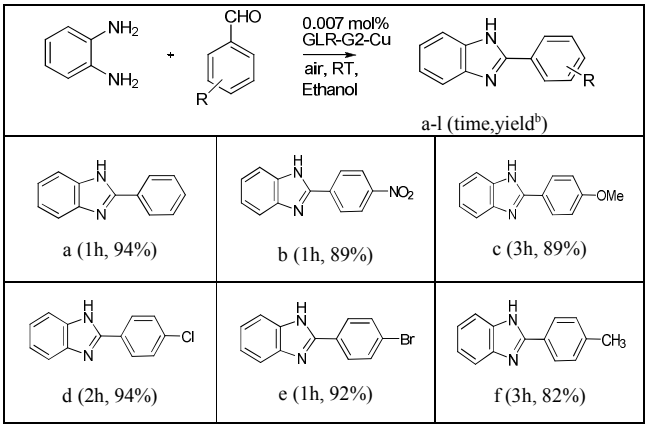
Table 7 Generation effect on the synthesis of benzimidazole derivatives[a]

Benzimidazole derivative from	%Yield		
	GLR-G0-Cu	GLR-G1-Cu	GLR-G2-Cu
Benzaldehyde	80	87	94
Cyclohexanone	84	90	96

[a] Reaction conditions: o-phenylenediamine (1 mmol), benzaldehyde (1.0 mmol) / cyclohexanone (1.2 mmol), Ethanol-3ml, Room temperature (30 ^{O}C), Catalyst- 0.007 mol%. Isolated Yield.

Thus, in order to attain good level of conversion, GLR-G2-Cu catalyst (0.007 mol%) in ethanol at room temperature (30 ^{O}C) in the presence of air have been found to be the optimum (Table 5, 6 and 7). After optimizing the reaction conditions, scope of different substrates was examined (Table 8). All the substrates showed completion of reaction within few hours. Most of the reactions of o-phenylenediamine and aromatic aldehydes resulted in good-to-excellent yields, irrespective of whether an electron-withdrawing or an electron-donating group was present, *ie*., both electron withdrawing and electron releasing substituent showed good rate of conversion. But the position of substitution on the phenyl ring of benzaldehyde affects the reaction yield. Fascinatingly, chloro (Table 8, d), bromo (Table 8, e), nitro (Table 8, b), and methoxy (Table 8, c) groups at para position furnished high yields. However chloro (Table 8, j) and methoxy (Table 8, k) groups at the ortho position provided low yield compared with the same at para position. Also chloro group at ortho position (Table 8, j) provided lower yield than the same at meta position (Table 8, i). To check whether the reaction is possible with aliphatic aldehydes, acetaldehyde was chosen and furnished with high yield (98% in 1hour).

Table 8 Synthesis of benzimidazole derivatives using aldehydes[a]



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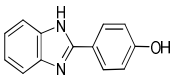
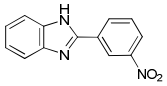
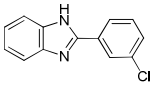
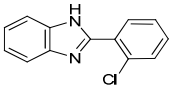
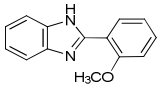
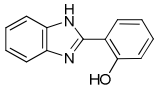
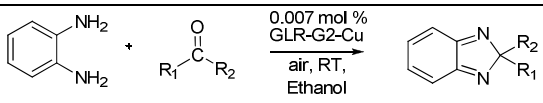
 g (2h, 84%)	 h (3h, 86%)	 i (3h, 92)
 j (3h, 86%)	 k (3h, 82%)	 l (3h, 84%)

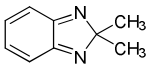
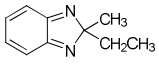
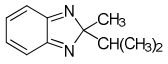
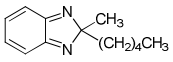
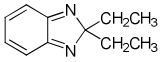
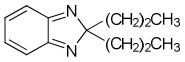
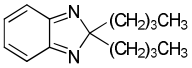
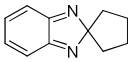
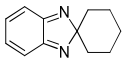
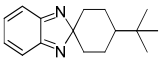
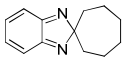
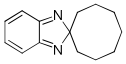
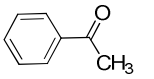
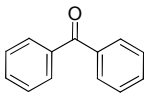
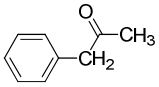
[a] Reaction conditions: o-phenylenediamine (1 mmol), aldehyde (1.0 mmol), Ethanol-3 ml, Room temperature (30 ^{O}C), air, GLR-G2-Cu- 0.007 mol%. [b] Isolated Yield.

With the optimum reaction conditions in hand, we have investigated the scope of dendritic copper-catalyzed conjugations of o-phenylenediamine towards aliphatic, aromatic and cyclic ketones also. As shown in Table 9, the examined substrates provided good to excellent yields. For ketones, the reactivity depended on their steric and electronic effect, particularly in the case of cyclic ketones, there will be substantial angle strain and addition of a nucleophile to these carbonyl bonds creates a tetrahedral center with less strain in the ring. 6-membered rings have the least ring strain, since the carbons in the 6-membered ring can all achieve what is closest to the ideal sp^3 bond angle. Hence, in going from an sp^2 hybridised centre to an sp^3 hybridised centre, cyclohexanone becomes more stable, because the conformation of that ring favours the sp^3 centre. However, for cyclopentanone, cycloheptanone and cyclooctanone these are somewhat further away from the sp^3 bond angle and actually favour the sp^2 hybridisation since torsional strain increases for them when they go from being sp^2 hybridised to sp^3 hybridised. Acetophenone, benzophenone and benzyl methyl ketone were reluctant to undergo this conjugation, shows no reaction even after 6h of reaction time. The substrates with higher charge density on the carbonyl carbon and larger steric hindrance are the reason for reluctance in reactivity in the case of these ketones. In the case of dialkyl ketones, the reactivity was found to decrease as the chain length increases. In the case of isopropyl methyl ketone, the reactivity was low due to bulky isopropyl group. The vital role of the catalyst, leading to the formation of the desired product, was confirmed by conducting a blank experiment without the catalyst. In the absence of the catalyst, the reaction was sluggish and gave only trace amount of the product. We have further compared the heterogeneous reaction with the reported homogeneous copper acetate catalyst also (Table 9)[40a] and the result shows that the dendritic effect enhances the catalytic behaviour to a certain extent.

Table 9 Synthesis of benzimidazole derivatives using ketones[a]



1 2 a_1-l_1 (time, yield[b]) (time, yield)[40a]

 a_1 (30 min, 95%) (3h, 91%)	 b_1 (60 min, 93%) (5h, 95%)	 c_1 (120 min, 81%) (6h, 78%)
 d_1 (120 min, 92%) (6h, 93%)	 e_1 (120 min, 87%) (6h, 87%)	 f_1 (120 min, 84%) (6h, 85%)
 g_1 (120 min, 68%) (6h, 61%)	 h_1 (120 min, 84%)	 i_1 (30 min, 96%) (3h, 89%)
 j_1 (10 min, 96%) (1h, 93%)	 k_1 (240 min, 89%) (6h, 88%)	 l_1 (240 min, 73%) (8h, 73%)
 2 (6h, no reaction)	 2 (6h, no reaction)	 2(6h, no reaction)

[a] Reaction conditions: o-phenylenediamine (1.0 mmol), ketone (1.2 mmol), Ethanol-3 ml, RT (30 ^{O}C), GLR-G2-Cu- 0.007 mol% .[b] Isolated yield.

3.2.2 Recyclability of the Catalyst

After completion of the reaction, the solution was filtered, washed with ethyl acetate and dried in vacuum to afford the corresponding compound. The catalyst recovered was dried under air, weighed and reused without loss of a significant catalytic activity. Details regarding catalyst recovery with percentage yield and the corresponding bar diagram (ESI) are depicted in Table 10. Successive runs were carried out in order to see the recyclability of the catalyst. After fifth cycle, 97.9% of catalyst was recovered and reused with 93% and 92% conversion for substrates cyclohexanone and benzaldehyde respectively.

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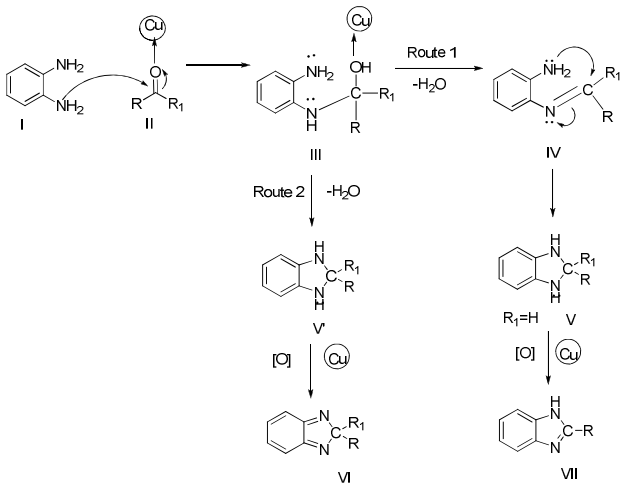
Table 10 Recycling of GLR-G2-Cu catalyst[a]

Substrate	No.of Cycles	Catalyst weight (mg)	Catalyst recovered (mg)	Recovery (%)	Product yield (%)[b]
Cyclohexanone	1	10	9.9	99.0	96
	2	9.9	9.8	99.0	96
	3	9.8	9.6	98.0	94
	4	9.6	9.5	99.0	94
	5	9.5	9.3	97.9	93
Benzaldehyde	1	10	9.9	99.0	94
	2	9.9	9.7	98.0	94
	3	9.7	9.6	99.0	94
	4	9.6	9.4	97.9	93
	5	9.4	9.2	97.9	92

[a] Reaction conditions: o-phenylenediamine (1.0 mmol), cyclohexanone (1.2 mmol, reaction time: 30 min), benzaldehyde (1.0 mmol, reaction time: 1hr), Ethanol-3 ml, RT (30 ^{O}C), [b] Isolated Yield.

3.2.3 The Proposed Mechanism

In order to explore the mechanism of the dendritic copper-catalyzed conjugation of aromatic 1,2-diamines with aldehydes or ketones, a control experiment was performed without catalyst or oxygen. Treatment of o-phenylenediamine with benzaldehyde in the absence of air (nitrogen atmosphere) produced only trace amount of the product. But the reaction can happen in an aerated condition at a higher temperature even in the absence of catalyst. This result showed that the participation of copper catalyst can increase the rate of the reaction by increasing the rate of formation of the intermediate. Therefore, a possible mechanism for the copper-catalyzed conjugation is proposed in Scheme 4. As far as the chemistry of copper (II) is concerned, the reaction presumably proceeds *via* activation of aldehyde by Cu catalyst. But in the presence of more electrophilic carbonyl carbon, attack of amine nucleophile results in intermediate III. The intermediate III formed can then be converted to V or V' via route 1 or route 2 respectively. Route 1 via the attack of nucleophilic nitrogen of first amine followed by attack of nuceophilic nitrogen of second amine and route 2 via the direct attack of nuceophilic nitrogen of second amine of o-phenylenediamine. Subsequently, dihydrobenzimidazole V or V' formed undergoes aromatization under aerial oxidation to give benzimidazole VI or VII as shown in Scheme 4. Further, the cooperative behaviour of dendritic ligands enhances the catalytic activity. Aromatic ketones like acetophenone, benzophenone and benzyl methyl ketone are not retort to this reaction.



Scheme 4 Mechanism of synthesis of benzimidazole derivatives

4. Conclusions

Polyepichlorohydrin was coupled to Merrifield resin in order to increase the loading capacity. Novel families of dendrigraft G0, G1 and G2 amine polymer having glycerol initiated polyepichlorohydrin as core have been synthesized and characterized. Amount of amino group in the highly functionalized G0, G1 and G2 series was found to be increasing from G0 to G2 generation. The copper complexes of these dendrigraft polymers were prepared. Characterization of GLR-G2-Cu catalyst was done. All the generations of GLR-Gn-Cu (n= 0, 1 and 2) were found to be excellent catalysts for the synthesis of benzimidazole derivatives *via* the reaction between o-phenylenediamine with aldehydes or aliphatic or cyclic ketones. The reaction occurred even with low generation *ie.,* GLR-G0-Cu polymer. A detailed study of the synthesis of benzimidazole derivatives was done with GLR-G2-Copper catalyst. Comparison of GLR-G2-Cu catalyst with nondendritic copper acetate was also done for the synthesis of 2, 2-disubstituted benzimidazoles. The main features of the synthesis include: (1) air was used as the terminal oxidant, (2) even though the reaction occurred to a good extent in water, ethanol was used as the solvent for the reaction, (3) only small amount of catalyst was needed to drive the reaction (0.007 mol%), (4) water was the only by-product in this reaction, (5) all the reactions were performed at room temperature (30 ^{O}C) and it showed outstanding tolerance of functional groups on aldehydes, (6) the synthetic protocol for benzimidazole derivatives is straightforward, safe, environmentally clean, and free from halogenated solvents or any other additives such as a co-catalyst or acid and (7) procedural simplicity, simple recovery and reusability of catalysts meet the requirements of benign chemistry. Further investigation on application of this catalyst for the synthesis of benzimidazole using substituted aromatic ketones or carbaldehydes is in progress.

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Highly functionalized heterogeneous dendrigraft catalyst with peripheral copper moieties for the facile synthesis of 2-substituted benzimidazoles and 2, 2-disubstituted benzimidazoles

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Highly functionalized heterogeneous copper loaded Dendrigraft amidoamine catalyst for the synthesis of 2-substituted and 2, 2-disubstituted benzimidazoles is reported.