Electronic Supplementary Material (ESI) for Polymer Chemistry

Supporting Information

"Poly(Azlactone)s: Versatile Scaffolds for Tandem Post-Polymerization Modification and Glycopolymer Synthesis"

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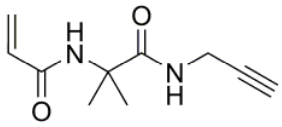
N-(2-methyl-1-oxo-1-(prop-2-ynylamino)propan-2-yl)acrylamide



2-Vinyl-4,4-dimethyl azlactone (VDMA) (30 mg, 216 μmol) and propargyl amine (11.9 mg, 216 μmol) were dissolved in 3 mL of toluene and left to stir overnight at room temperature. Precipitation of a white crystalline solid was observed and the product was isolated upon removal of the solvent under reduced pressure (41.8 mg, quantitative yield).

^{1}H NMR (400.03 MHz, $CDCl_3$, 298 K) δ = 7.02 (br s, 1H, NH), 6.39 (br s, 1H, NH), 6.28 (dd, 1H, *J* = 16.6, 1.5 Hz, CH), 6.13 (dd, 1H, *J* = 17.1, 10.4 Hz, CH), 5.66 (dd, 1H, *J* = 10.4, 1.5 Hz, CH), 4.03 (dd, 2H, *J* = 2.5 Hz, CH_2), 2.21 (t, 1H, *J* = 2.5 Hz), 1.61 (s, 6H). ^{13}C NMR (100.59 MHz, $CDCl_3$, 298 K) δ = 174.2, 165.6, 131.0, 127.2, 79.5, 71.6, 57.5, 29.6, 25.2.). IR (solid) ν = 3263, 2437, 2391, 1650, 1607, 1544, 1438, 1218, 959 cm^{-1}. HRMS (ES+) calcd for $C_{10}H_{14}N_2O_2$ $[M + Na]^+$ 217.0947, observed 217.0953.

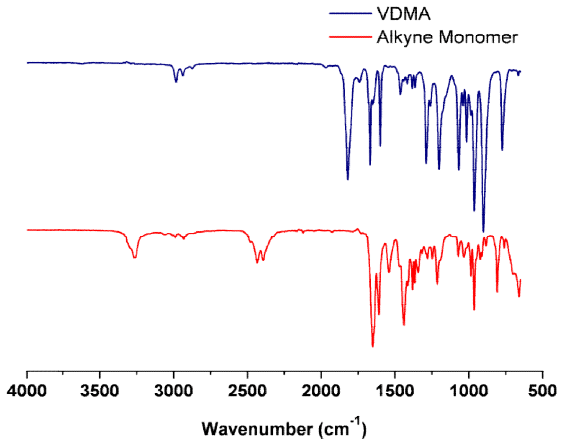


Figure S1. IR spectra of VDMA before (blue) and after (red) reaction with propargyl amine

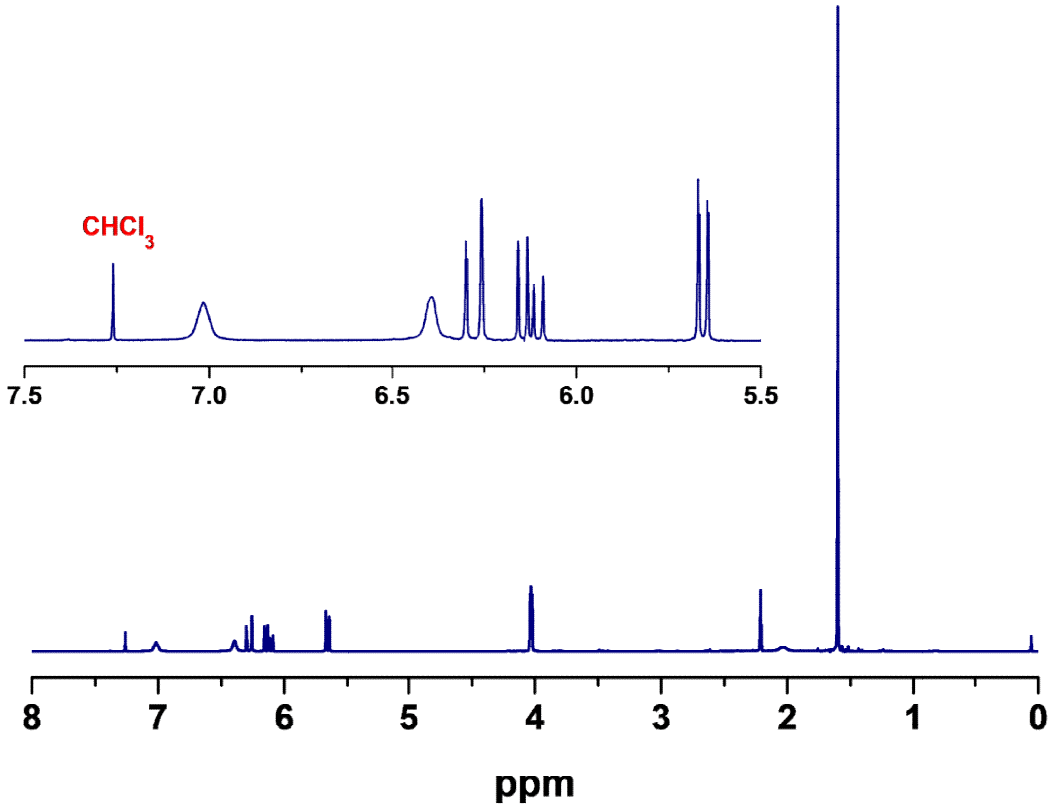
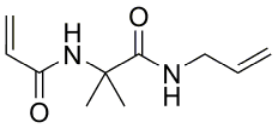


Figure S2. NMR analysis of the ring opened product upon treatment of VDMA with propargyl amine.

N-(1-(allylamino)-2-methyl-1-oxopropan-2-yl)acrylamide



2-Vinyl-4,4-dimethyl azlactone (VMDA) (30 mg, 216 μmol) and allyllamine (12.3 mg, 216 μmol) were dissolved in 3 mL of toluene and left to stir overnight at room temperature. Precipitation of a white crystalline solid was observed and the product was isolated upon removal of the solvent under reduced pressure (42.3 mg, quantitative yield).

^{1}H NMR (400.03 MHz, $CDCl_3$, 298 K) δ = 6.79 (br s, 1H, NH), 6.55 (br s, 1H, NH), 6.26 (dd, 1H, *J* = 16.6, 1.5 Hz, CH), 6.12 (dd, 1H, *J* = 16.6, 10.4 Hz, CH), 5.81 (tq, 1H, *J* = 10.5, 5.0 Hz, CH), 5.63 (dd, 1H, *J* = 10.4, 1.5 Hz, CH), 5.13 (qdd, 1H, *J* = 23.1, 17.1, 1.5 Hz, CH), 3.87 (tt, 2H, *J* = 5.5, 1.5 Hz, CH_2), 1.61 (s, 6H). ^{13}C NMR (100.59 MHz, $CDCl_3$, 298 K) δ = 174.4, 165.4, 134.0, 131.2, 126.9, 116.1, 57.5, 42.1, 25.3. IR (solid) ν = 3276, 3060, 2979, 2928, 1655, 1620, 1536, 1251 cm^{-1}. HRMS (ES+) calcd for $C_{10}H_{16}N_2O_2$ $[M + Na]^+$ 219.1104, observed 219.1109.

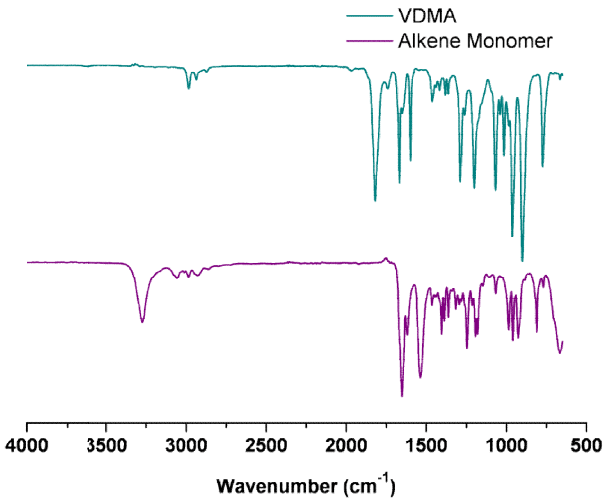


Figure S3. IR spectra of VDMA before (blue) and after (red) reaction with allyl amine

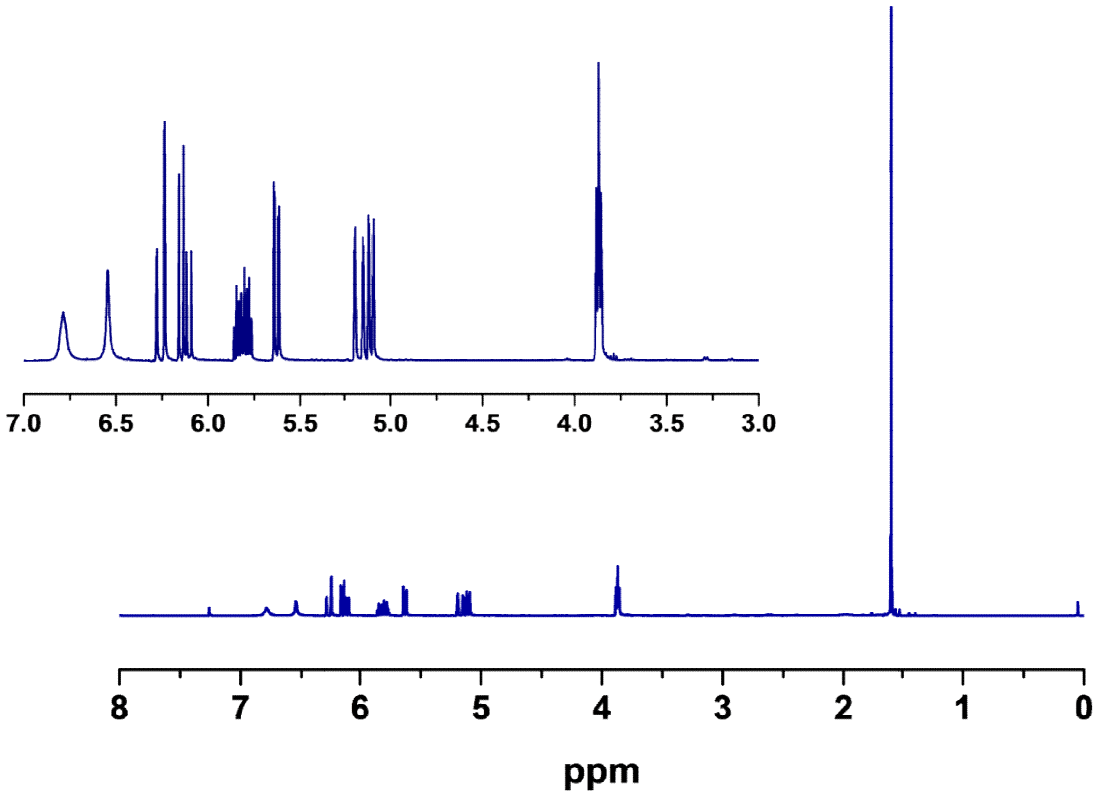
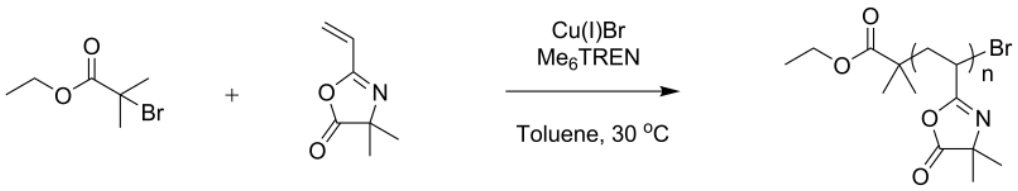


Figure S4. IR and NMR analysis of the ring opened product upon treatment of VDMA with allyl amine.

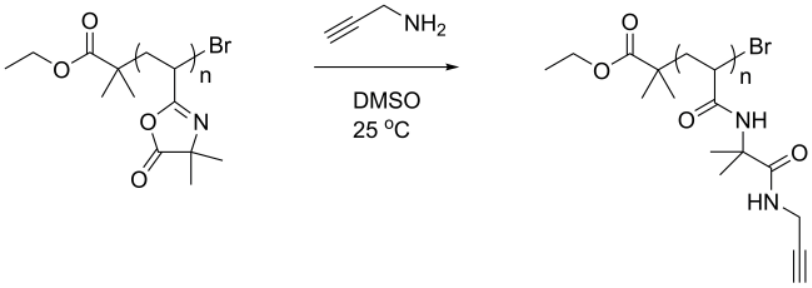
Synthesis of poly(VDMA) by ATRP



VDMA (3.00 g, 21.6 mmol), ethyl 2-bromoisobutyrate (0.0841 g, 0.43 mmol), Cu(I)Br (0.0619 g, 0.43 mmol), mesitylene (0.518 g, 4.31 mmol) and toluene (6 mL) were added to an oven dried Schlenk tube and subjected to four freeze-pump-thaw cycles and left under a blanket of nitrogen. Me_6TREN was added to the Schlenk tube *via* a degassed syringe and the brown solution immersed in an oil bath at 30 °C. Samples were taken periodically for analysis by ^{1}H NMR and SEC and after 140 minutes (89 % monomer conversion) the polymerisation was quenched by exposing the solution to air. SEC analysis (Quenched at 140 min) – M_n 5900 gmol^{-1}, PDi 1.32.

The solution was immediately employed for the ring opening of various amines to yield the desired functionalised polymers.

Propargyl Amine Modification of poly(VDMA)



4.5 mL of the crude poly(VDMA) solution (containing 10.8 mmol of azlactone functionality) was added to a round bottomed flask and diluted with 5 mL of DMSO. Propargylamine (0.891 g, 16.2 mmol) was added to the polymer solution in 10 mL of DMSO and the solution allowed to stir at room temperature overnight. The solution was added dropwise into ethyl acetate, with precipitation of the polymer. The solid was collected by centrifugation and isolated as a crystalline solid.

Infra-red analysis of the obtained polymer showed complete disappearance of the signals corresponding to the azlactone ring, along with the appearance of a strong signal corresponding to the two amide moieties generated upon ring opening. SEC analysis revealed a clear mass increase upon ring opening with propargyl amine, and a well-defined final polymer observed.

SEC Analysis (DMF) – Mn 12,500 $gmol^{-1}$, PDi 1.20.

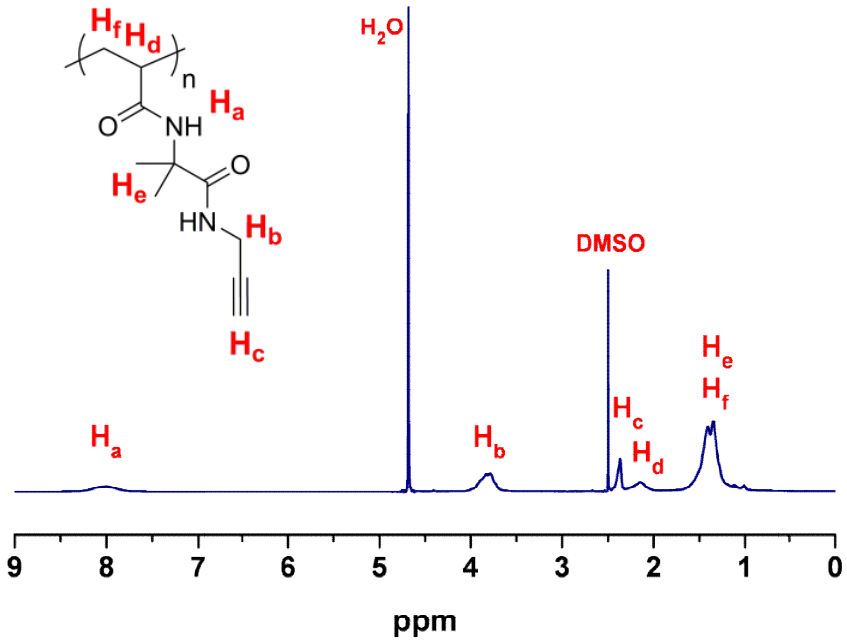
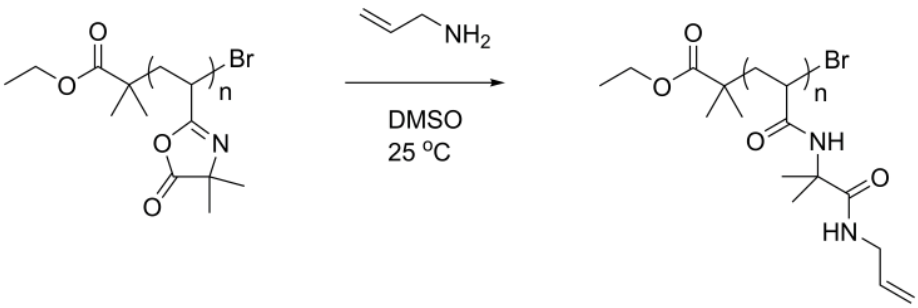


Figure S5. ^{1}H NMR analysis of the post polymerisation modification of poly(VDMA) with propargyl amine.

Allyl Amine Modification of poly(VDMA)



4.5 mL of the crude poly(VDMA) solution (containing 10.8 mmol of azlactone functionality) was added to a round bottomed flask and diluted with 5 mL of DMSO. Allylamine (0.92 g, 16.2 mmol) was added to the polymer solution in 10 mL of DMSO and the solution allowed to stir at room temperature overnight. The solution was added dropwise into ethyl acetate, with precipitation of the polymer. The solid was collected by centrifugation and isolated as a crystalline solid.

Infra-red analysis of the obtained polymer showed complete disappearance of the signals corresponding to the azlactone ring, along with the appearance of a strong signal corresponding to the two amide moieties generated upon ring opening. SEC analysis revealed a clear mass increase upon ring opening with allylamine, and a well-defined final polymer observed.

SEC Analysis (DMF) – M_n 12,800 $gmol^{-1}$, PDi 1.15.

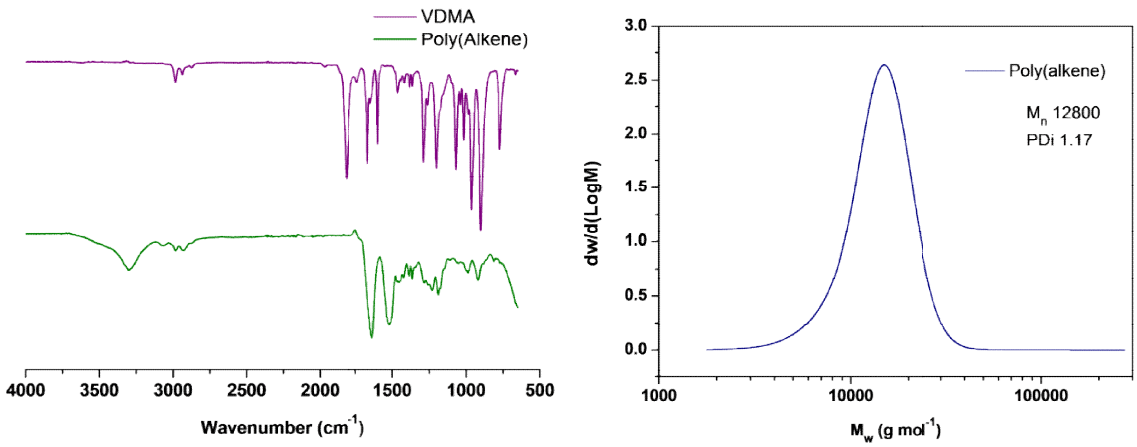


Figure S6. IR and SEC analysis of the post polymerisation modification of poly(VDMA) with allyl amine.

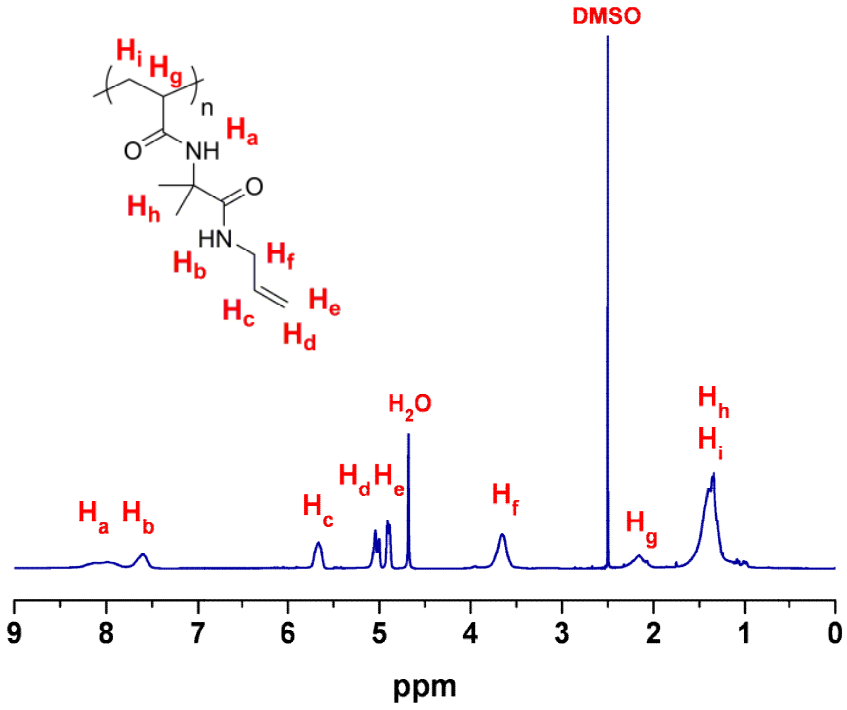
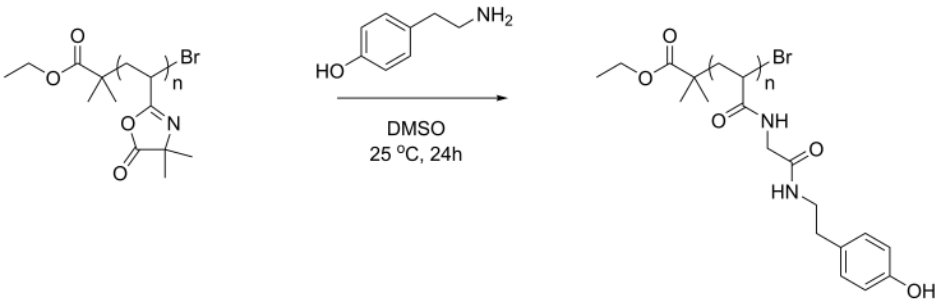


Figure S7. ^{1}H NMR analysis of the post polymerisation modification of poly(VDMA) with propargyl amine.

Tyramine Modification of poly(VDMA)



4.5 mL of the crude poly(VDMA) solution (containing 10.8 mmol of azlactone functionality) was added to a round bottomed flask and diluted with 5 mL of DMSO. Tyramine (2.218 g, 16.2 mmol) was added to the polymer solution in 10 mL of DMSO and the solution allowed to stir at room temperature overnight. The solution was added dropwise into ethyl acetate, with precipitation of the polymer. The solid was collected by centrifugation and isolated as a crystalline solid.

Infra-red analysis of the obtained polymer showed complete disappearance of the signals corresponding to the azlactone ring, along with the appearance of a strong signal corresponding to the two amide moieties generated upon ring opening. SEC analysis revealed a clear mass increase upon ring opening with tyramine, and a well-defined final polymer observed. A strong UV absorbance (280 nm) was also observed for the functionalised polymer, further evidence of incorporation of the aromatic group to the polymer backbone.

SEC Analysis (DMF) – M_n 11,700 $gmol^{-1}$, PDi 1.28.

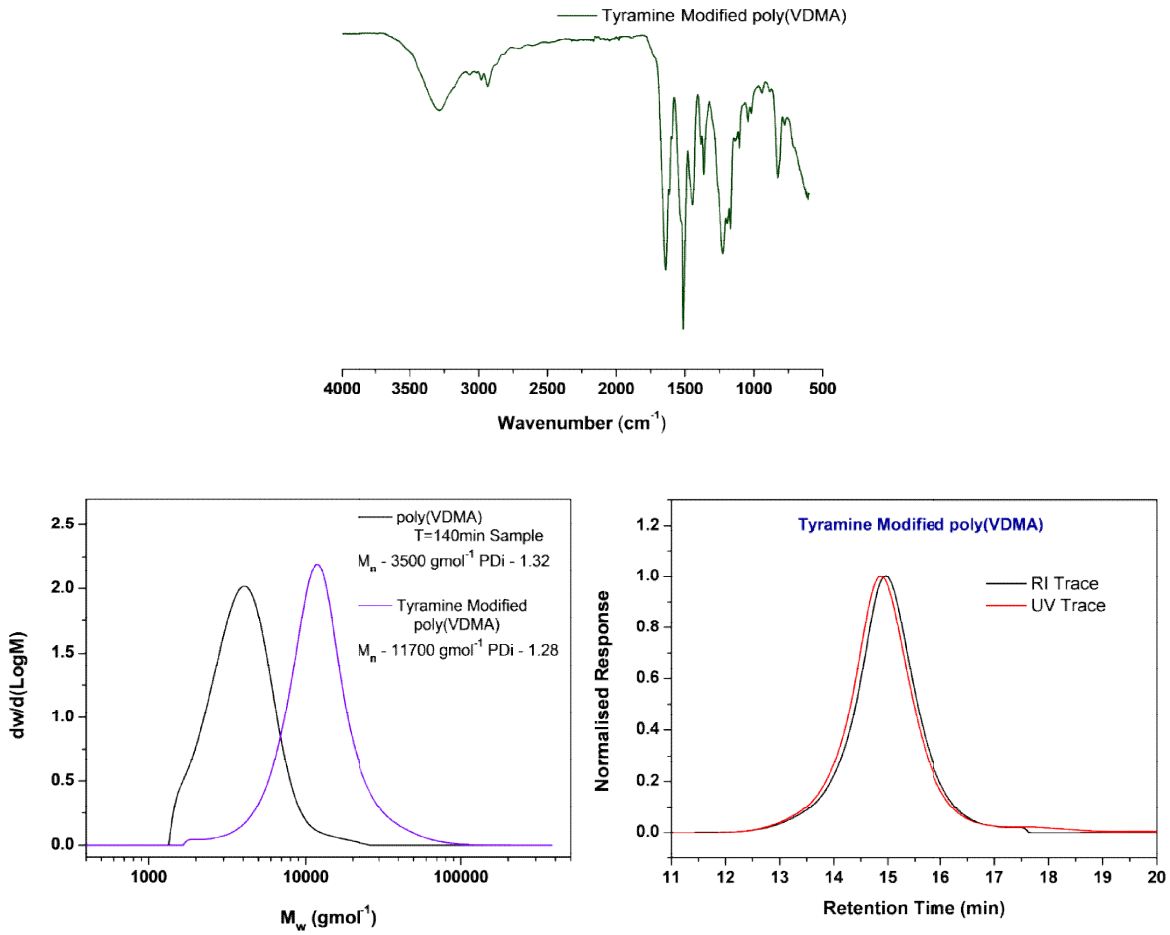


Figure S8. IR and SEC analysis of the post polymerisation modification of poly(VDMA) with tyramine.

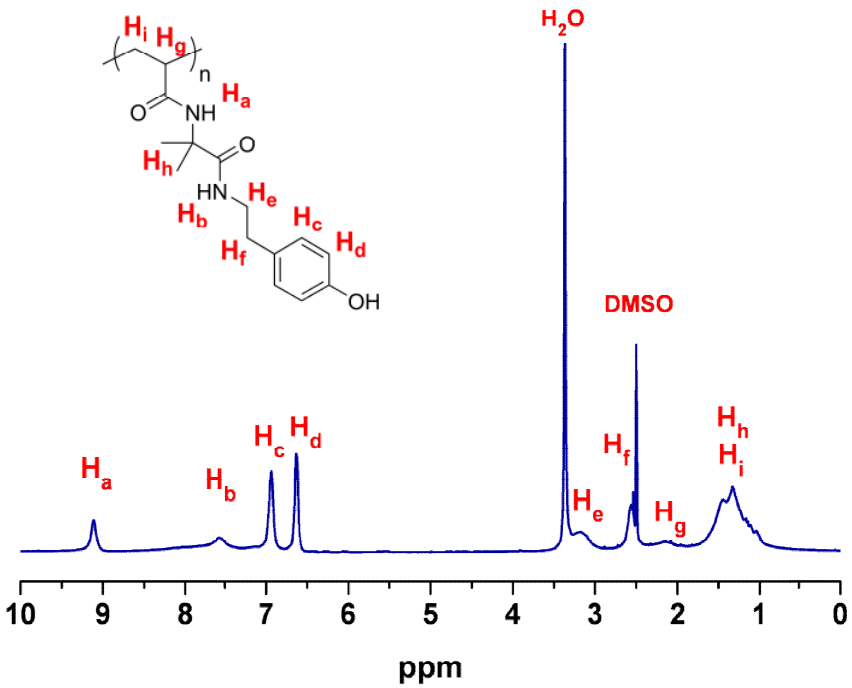
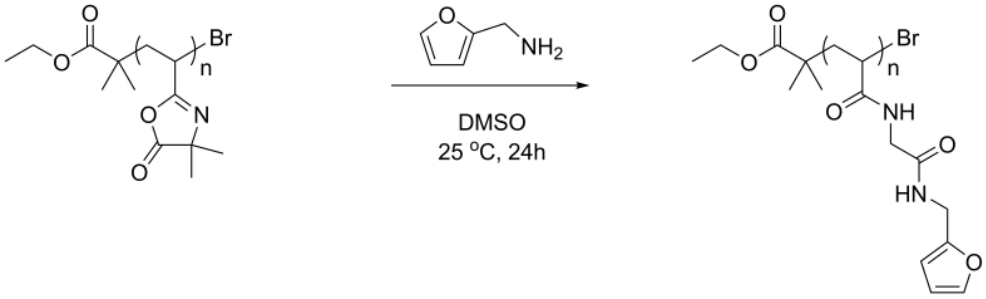


Figure S9. ^{1}H NMR analysis of the post polymerisation modification of poly(VDMA) with tyramine.

Furfuryl amine modification of poly(VDMA)



4.5 mL of the crude poly(VDMA) solution (containing 10.8 mmol of azlactone functionality) was added to a round bottomed flask and diluted with 5 mL of DMSO. Furfurylamine (1.570 g, 16.2 mmol) was added to the polymer solution in 10 mL of DMSO and the solution allowed to stir at room temperature overnight. The solution was added dropwise into ethyl acetate, with precipitation of the polymer. The solid was collected by centrifugation and isolated as a crystalline solid.

Infra-red analysis of the obtained polymer showed complete disappearance of the signals corresponding to the azlactone ring, along with the appearance of a strong signal corresponding to the two amide moieties generated upon ring opening. SEC analysis revealed a clear mass increase upon ring opening with furfurylamine, and a well-defined final polymer observed.

SEC Analysis (DMF) – M_n 10,200 $gmol^{-1}$, PDi 1.35.

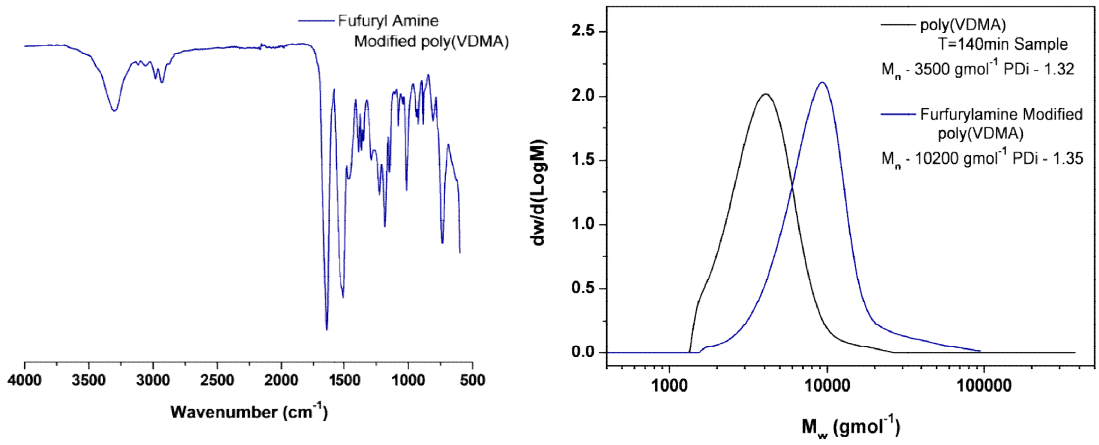


Figure S10. IR and SEC analysis of the post polymerisation modification of poly(VDMA) with furfurylamine.

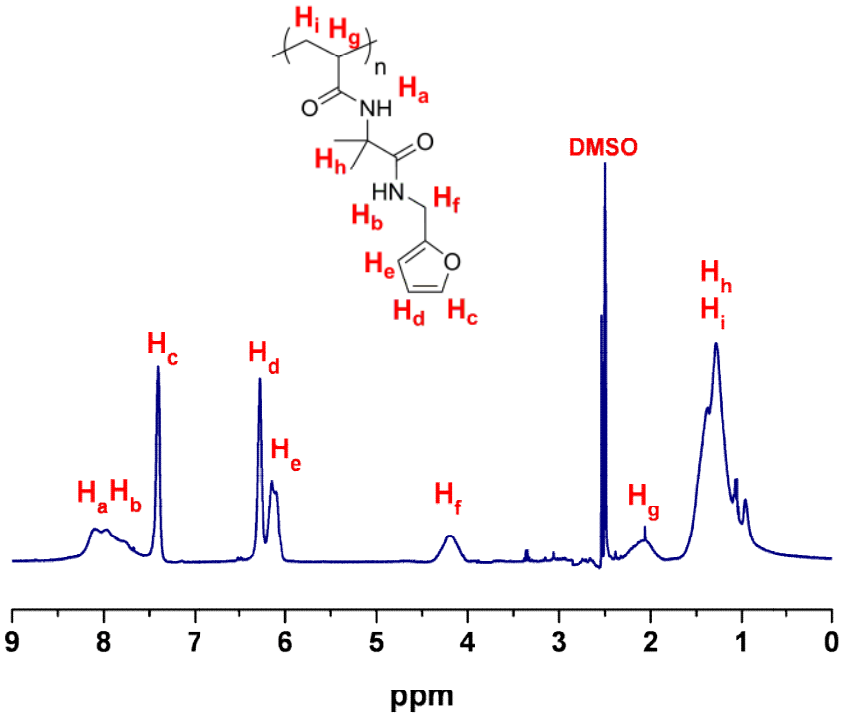


Figure S11. ^{1}H NMR analysis of the post polymerisation modification of poly(VDMA) with furfuryl amine.

Synthesis of Glycopolymers

Glucosamine modified poly(VDMA)

4.5 mL of the crude poly(VDMA) solution (containing 10.8 mmol of azlactone functionality) was added to a round bottomed flask and diluted with 5 mL of DMSO. Glucosamine hydrochloride (3.487 g, 16.2 mmol) was added to the polymer solution in 10 mL of DMSO, along with triethylamine (1.63 g, 16.2 mmol) and the solution allowed to stir at room temperature overnight. Volatiles were then removed and the crude polymer solution diluted with water and dialysed against water (MWCO 1000 Da) for 3 days to remove low molecular weight species. The water was removed by lyophilisation to yield the product as a white fluffy powder.

Infra-red analysis of the obtained polymer showed complete disappearance of the signals corresponding to the azlactone ring, along with the appearance of a strong signal corresponding to the two amide moieties generated upon ring opening. SEC analysis revealed a clear mass increase upon ring opening with glucosamine.

SEC Analysis (Aqueous) – M_n 11,900 $gmol^{-1}$, PDi 1.40.

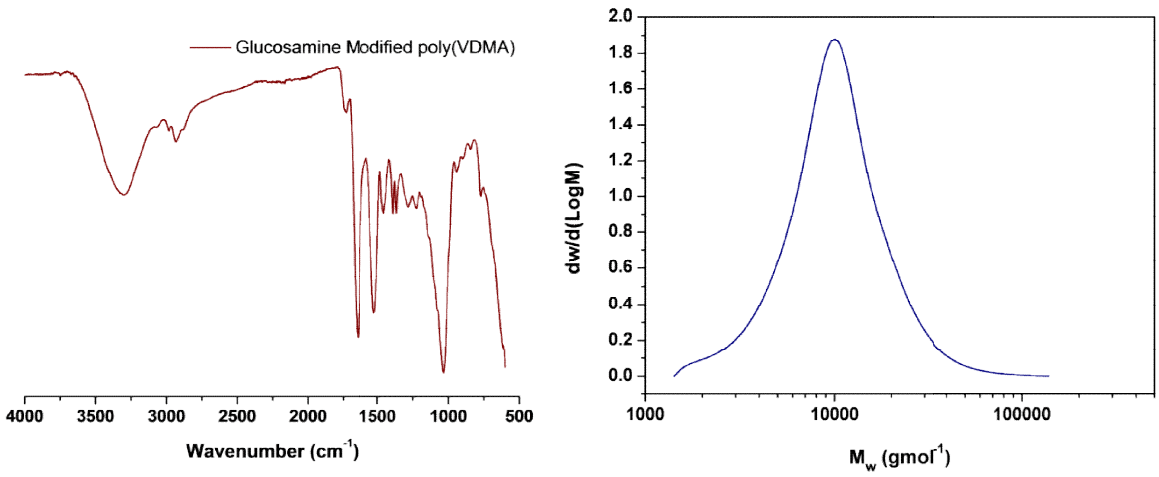


Figure S12. IR and SEC analysis of the post polymerisation modification of poly(VDMA) with glucosamine.

Galactosamine modified poly(VDMA)

4.5 mL of the crude poly(VDMA) solution (containing 10.8 mmol of azlactone functionality) was added to a round bottomed flask and diluted with 5 mL of DMSO. Galactosamine hydrochloride (3.487 g, 16.2 mmol) was added to the polymer solution in 10 mL of DMSO, along with triethylamine (1.63 g, 16.2 mmol) and the solution allowed to stir at room temperature overnight. Volatiles were then removed and the crude polymer solution diluted with water and dialysed against water (MWCO 1000 Da) for 3 days to remove low molecular weight species. The water was removed by lyophilisation to yield the product as a white fluffy powder.

Infra-red analysis of the obtained polymer showed complete disappearance of the signals corresponding to the azlactone ring, along with the appearance of a strong signal corresponding to the two amide moieties generated upon ring opening. SEC analysis revealed a clear mass increase upon ring opening with galactosamine, and a well-defined final polymer observed.

SEC Analysis (Aqueous) – M_n 11,400 $gmol^{-1}$, PDi 1.44.

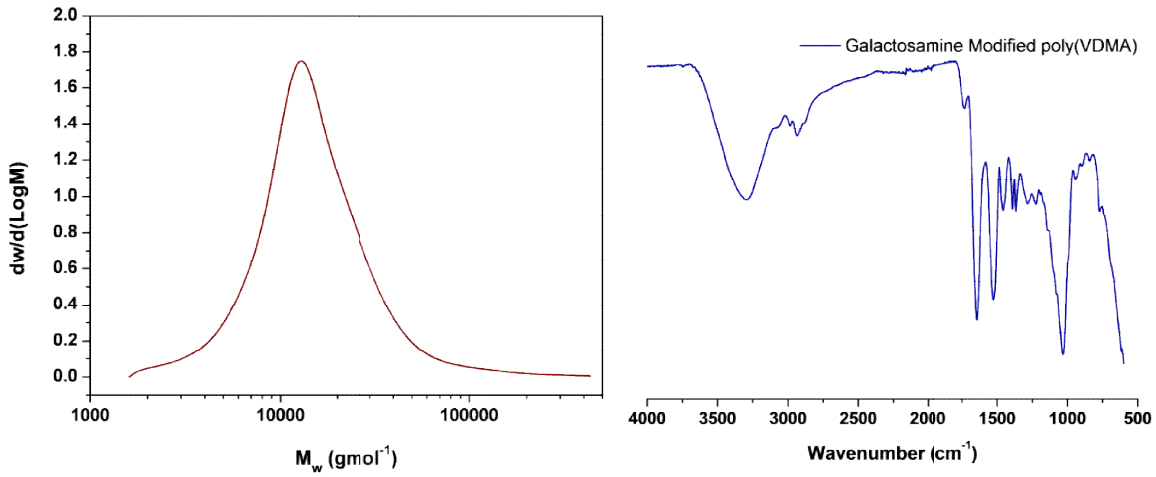


Figure S13. IR and SEC analysis of the post polymerisation modification of poly(VDMA) with galactosamine.

Mannosamine modified poly(VDMA)

4.5 mL of the crude poly(VDMA) solution (containing 10.8 mmol of azlactone functionality) was added to a round bottomed flask and diluted with 5 mL of DMSO. Mannosamine hydrochloride (3.487 g, 16.2 mmol) was added to the polymer solution in 10 mL of DMSO, along with triethylamine (1.63 g, 16.2 mmol) and the solution allowed to stir at room temperature overnight. Volatiles were then removed and the crude polymer solution diluted with water and dialysed against water (MWCO 1000 Da) for 3 days to remove low molecular weight species. The water was removed by lyophilisation to yield the product as a white fluffy powder.

Infra-red analysis of the obtained polymer showed complete disappearance of the signals corresponding to the azlactone ring, along with the appearance of a strong signal corresponding to the two amide moieties generated upon ring opening. SEC analysis revealed a clear mass increase upon ring opening with mannosamine, and a well-defined final polymer observed.

SEC Analysis (Aqueous) – M_n 11,600 $gmol^{-1}$, PDi 1.42.

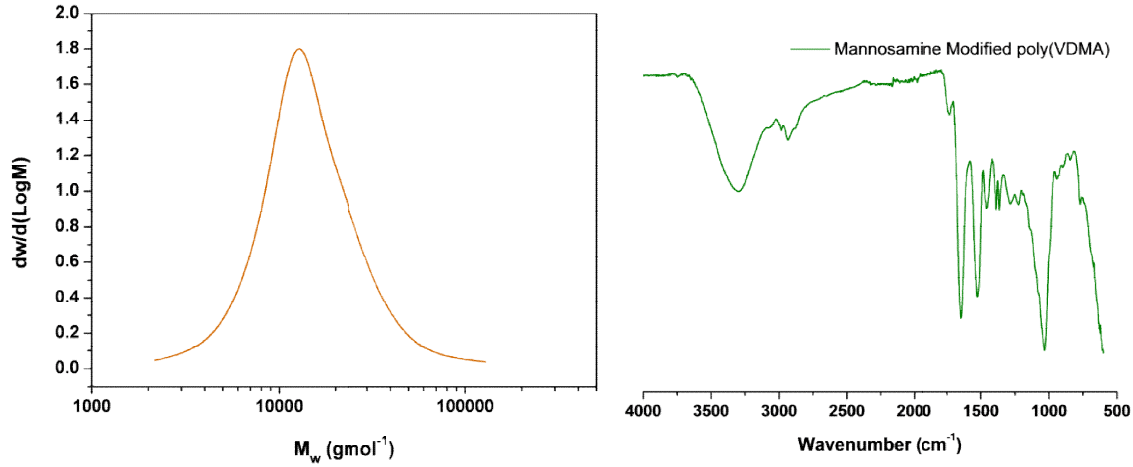


Figure S14. IR and SEC analysis of the post polymerisation modification of poly(VDMA) with mannosamine.

Hydrolysis of poly(VDMA)

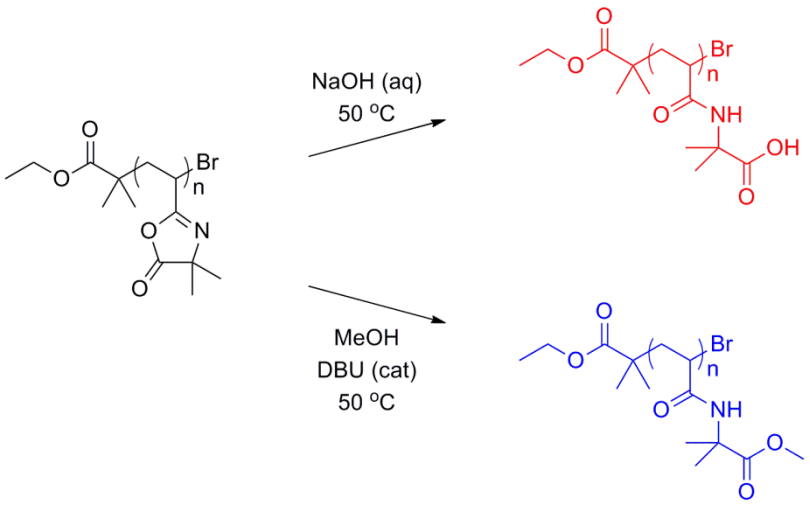


Figure S15. Ring opening of poly(VDMA) with NaOH (red) and methanol (blue) to yield acid- and ester-functional polymers respectively.

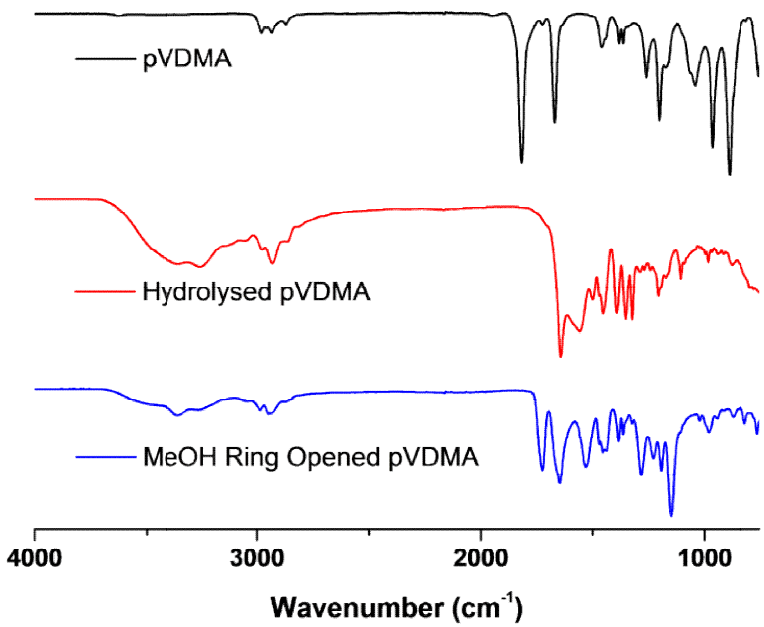


Figure S16. IR analysis of the products obtained from ring opening of poly(VDMA) with NaOH (red trace) and methanol (blue trace). The acid functional polymer showed a clear signal at around 1644 cm^{-1}, with the ester functional polymer displaying a signal at 1726 cm^{-1}