Electronic Supplementary Material (ESI) for Nanoscale Advances.

Supporting Information

Un-doped carbon quantum dots (CQDs) reinforcement having partially carbonized structure doubles the toughness of PVA membranes

Zeeshan Latif[1], Hasan B. Albargi[2,3], Zubair Khaliq[1], Kinza Shahid[1], Usama Khalid[1], Muhammad Bilal Qadir[4]*, Mumtaz Ali[4]*, Salman Noshear Arshad[5], Ali S. Alkorbi[6], Mohammed Jalalah[3,7]*

[1] Department of Materials, School of Engineering and Technology, National Textile University, Faisalabad 37610, Pakistan. Z.L. (zeeshanlatif203@yahoo.com); Z.K. (zubntu@yahoo.com); K.S. (kinzashahid1560@gmail.com); U.K. (usamakhalidqurashi@gmail.com)

[2] Department of Physics, Faculty of Science and Arts, Najran University, Najran 11001, Saudi Arabia. H.B.A. (hbalbargi@nu.edu.sa)

[3] Advanced Materials and Nano-Research Centre (AMNRC), Najran University, Najran 11001, Saudi Arabia. M.J. (msjalalah@nu.edu.sa)

[4] Department of Textile Engineering, School of Engineering and Technology, National Textile University, Faisalabad 37610, Pakistan. M.B.Q (bilal_ntu81@hotmail.com) ; M.A. (mumtaz.ali@ntu.edu.pk)

[5] Department of Chemistry and Chemical Engineering, Lahore University of Management Sciences, Lahore, 54792, Pakistan. S.N.A. (salman.arshad@lums.edu.pk)

[6] Department of Chemistry, Faculty of Science and Arts at Sharurah, Najran University, Sharurah 68342, Saudi Arabia. A.S.A. (assalem@nu.edu.sa)

[7] Department of Electrical Engineering, College of Engineering, Najran University, Najran 11001, Saudi Arabia

Corresponding Authors:

Muhammad Bilal Qadir (bilal_ntu81@hotmail.com),

Mumtaz Ali (mumtaz.ali@ntu.edu.pk)

Mohammed Jalalah (msjalalah@nu.edu.sa)

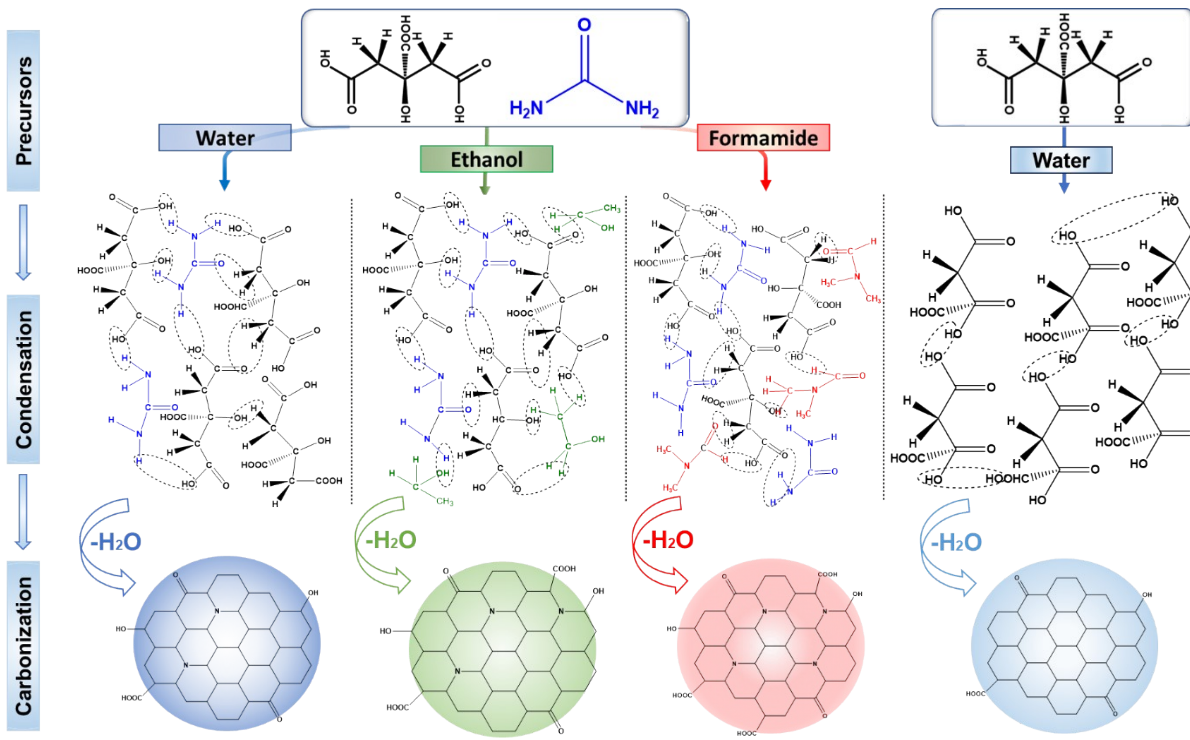

Figure S1. Formation mechanism of W-CQDs, E-CQDs, D-CQDs, and U-CQDs (Left to right) during synthesis. The solvents also contribute to the reaction and form new functional groups. The reaction is accomplished in three steps: (i) rearrangement of reactants, (ii) condensation reaction to make fluorophores, and (iii) carbonization (top to down).

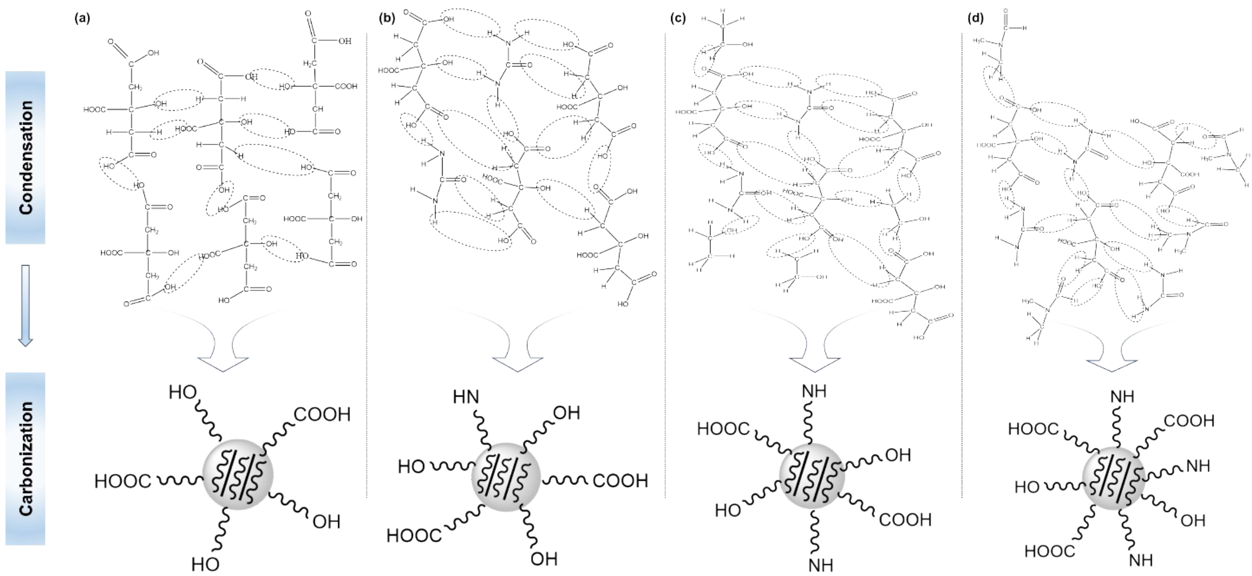

Figure S2. The schematic chemical structures of all synthesized CQDs (a) U-CQDs, (b) W-CQDs, (c) E-CQDs, and (d) D-CQDs.

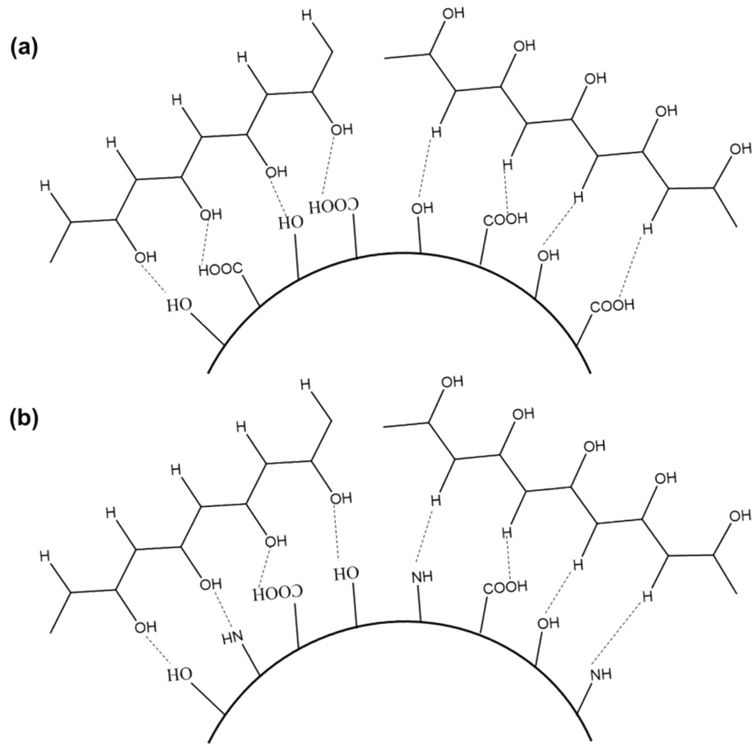

Figure S3. The schematic chemical interactions mechanism of (a) Un-dopped CQDs/PVA nanocomposites (b) nitrogen-dopped CQDs/PVA nanocomposites.

Table S1. Shows the comparison of average tensile strength of five samples for each sample fabricated using different surface chemistry, size and structure, and the concentration of the CQDs in PVA polymer.

Sample Name	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**	**Average**
Effect of different surface states						
PVA+U-CQDs	Load: 121.1 N Extension: 115%	Load: 120.9 N Extension: 119%	Load: 123 N Extension: 118%	Load: 122 Extension: 116%	Load: 123 Extension: 117%	Load: 122±1 N Extension: 117±1%
PVA+W-CQDs	Load: 90 N Extension: 78%	Load: 89 N Extension: 76%	Load: 88 N Extension: 79%	Load: 91 N Extension: 78%	Load: 92 N Extension: 79%	Load: 90±2 N Extension: 78±2%
PVA+E-CQDs	Load: 63 N Extension: 84%	Load: 65 N Extension: 82%	Load: 66 N Extension: 83%	Load: 65 N Extension: 84%	Load: 66 N Extension: 82%	Load: 65±1 N Extension: 83±1%
PVA+D-CQDs	Load: 99N Extension: 75%	Load: 100N Extension: 76%	Load: 98N Extension: 75%	Load: 102N Extension: 78%	Load: 101 N Extension: 76%	Load: 100±2 N Extension: 76±2%
Effect of different temperature						
PVA+U-CQDs 140 ^{o}C	Load: 116 N Extension: 76%	Load: 119N Extension: 78%	Load: 120 N Extension: 81%	Load: 123N Extension: 83%	Load: 122 N Extension: 82%	Load: 120±3 N Extension: 80±3%
PVA+U-CQDs 180 ^{o}C	Load: 150 N	Load: 148 N	Load: 149 N	Load: 152 N	Load: 151 N	Load: 150±2 N

	Extension: 120%	Extension: 119%	Extension: 118%	Extension: 121%	Extension: 122%	Extension: 120±2%
PVA+U-CQDs 220 ^{o}C	Load: 95 N Extension: 88%	Load: 100 N Extension: 90%	Load: 105 N Extension: 92%	Load: 101 N Extension: 87%	Load: 99 N Extension: 93%	Load: 100±5 N Extension: 90±5%
Effect of different concentrations						
PVA+2% U-CQDs 180 ^{o}C	Load: 120 N Extension: 113%	Load: 123 N Extension: 110%	Load: 117 N Extension: 114%	Load: 121 N Extension: 113%	Load: 119 N Extension: 115%	Load: 120±3 N Extension: 113±3%
PVA+4% U-CQDs 180 ^{o}C	Load: 150 N Extension: 120%	Load: 148 N Extension: 119%	Load: 149 N Extension: 118%	Load: 152 N Extension: 121%	Load: 151 N Extension: 122%	Load: 150±2 N Extension: 120±2%
PVA+6% U-CQDs 180 ^{o}C	Load: 115 N Extension: 128%	Load: 119 N Extension: 132%	Load: 114 N Extension: 129%	Load: 111 N Extension: 134%	Load: 116 N Extension: 127%	Load: 115±5 N Extension: 130±5%

Table S2. Shows the comparison of previous works and present work, where degree of polymerization of PVA, CQDs precursors, CQDs synthesis conditions, CQDs concentration, and the mixing method of CQDs were compared. However, the role of CQDs is rarely studied for mechanical reinforcement of PVA.

Sr.	**PVA Average degree of polymerization**	**CQDs precursors**	**CQDs synthesis conditions**	**CQDs conc.**	**CQDs dispersion**	**Ref.**
1	1700	Cellulose fibers, ammonia	Temp. 200 ^{o}C for 4 h	1 wt.%	Blending	[3]
2	1700	Phenylboronic acid, NaOH, water	Temp. 220 ^{o}C for 12 h	1 wt.%	Mechanical mixing	[4]
3	2600	Yeast powder, water	Temp. 200 ^{o}C for 8 h	2 vol.%	Mechanical mixing	[5]
4	2699	Sodium citrate, EDA, water	Temp. 160 ^{o}C for 8 h	3 vol.%	Mechanical mixing	[6]
5	1700 ± 50	Lignocellulose, magnesium hydroxide, EDA, water	Temp. 225 ^{o}C for 10 h	1 wt.%	Mechanical mixing	[7]
6	2023 to 2227	Citric acid derived from lemon pulp and water	Temp. 180 ^{o}C for 6 h	4 wt.%	Sonication and magnetic mixing	Present work