Supplementary Information

Ultra-robust Zinc-Ion Batteries with Co-solvent Water-in-Salt Electrolytes for Enhanced Stability and Capacity

Rahuldeb Roy[1,2], Tridip Das[3], William A Goddard III[3], Ashutosh Kumar Singh[1,2,4,*]

[1]*Centre for Nano and Soft Matter Sciences, Bangalore, Karnataka, 562162 India*

[2]*Manipal Academy of Higher Education, Manipal, Karnataka, 576104, India*

[3]*Materials and Process Simulation Center, MC 139-74, California Institute of Technology, Pasadena, California 91125, United States*

[4]*Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, Uttar Pradesh, 201002, India.*

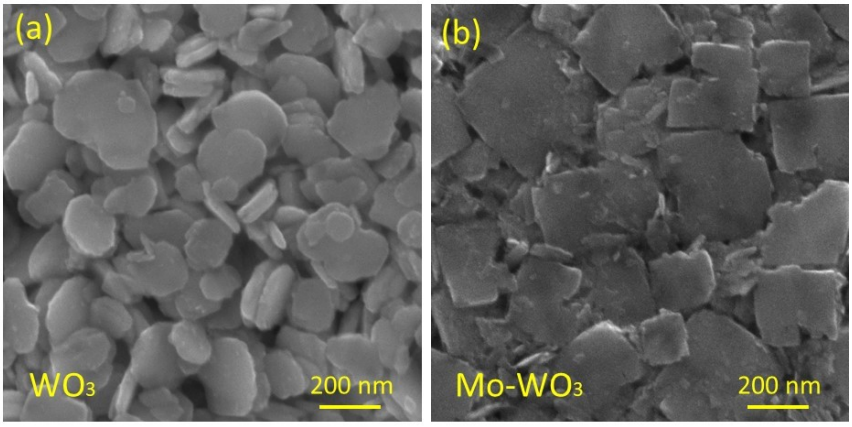

Fig. S1. High-magnification FESEM image of the (a) WO_3 and (b) Mo-WO_3.

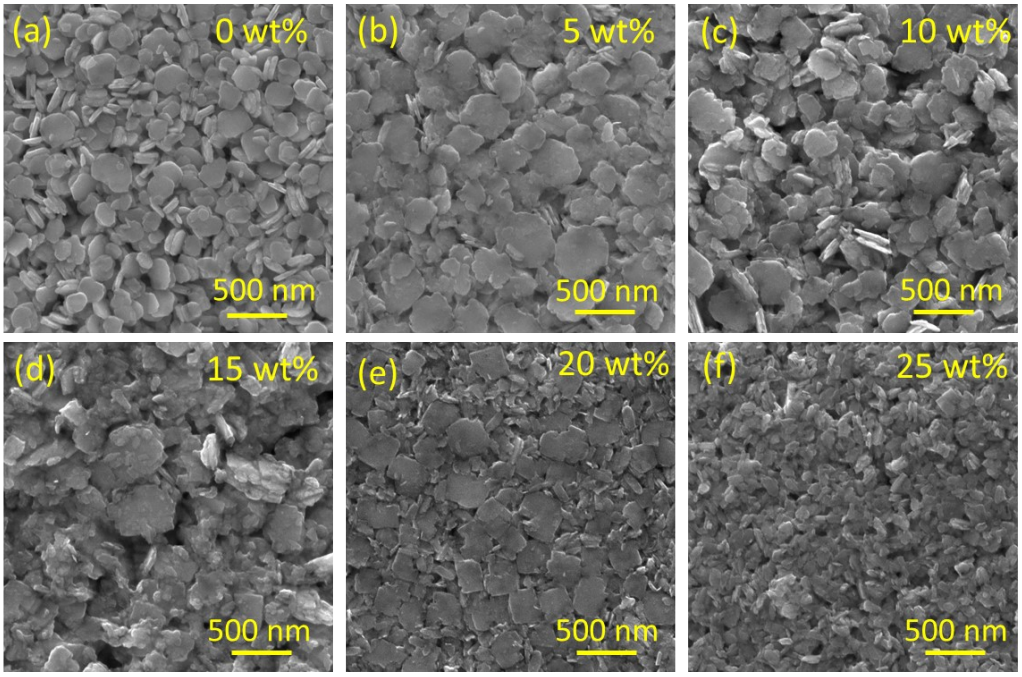

Fig. S2. FESEM images of different wt% of Mo into WO_3 structure.

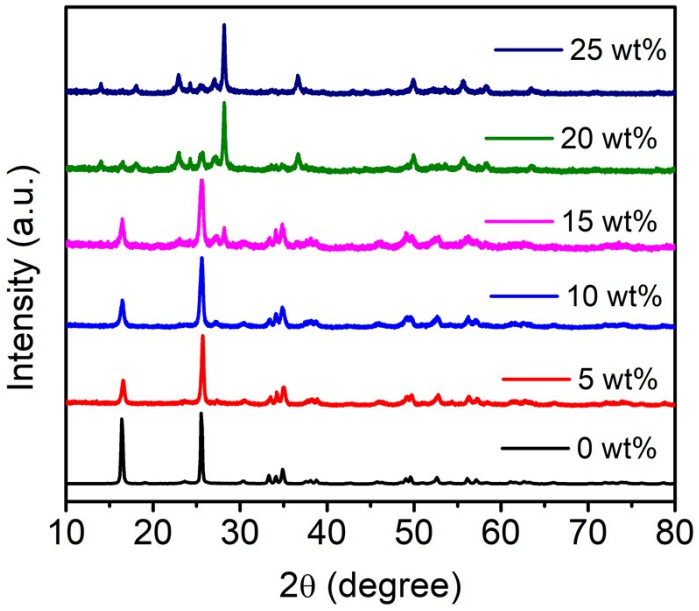

Fig. S3. XRD patterns of different wt% of Mo into WO_3 structure.

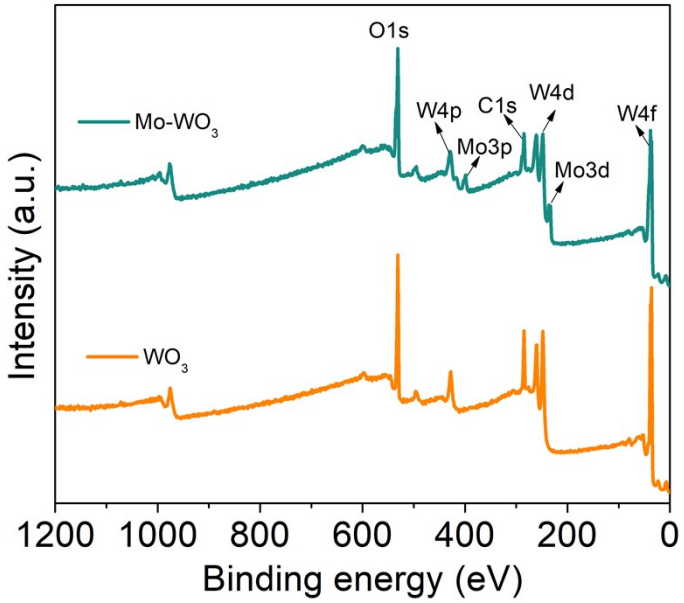

Fig. S4. XPS survey spectra of (a) WO_3 and (b) Mo-WO_3.

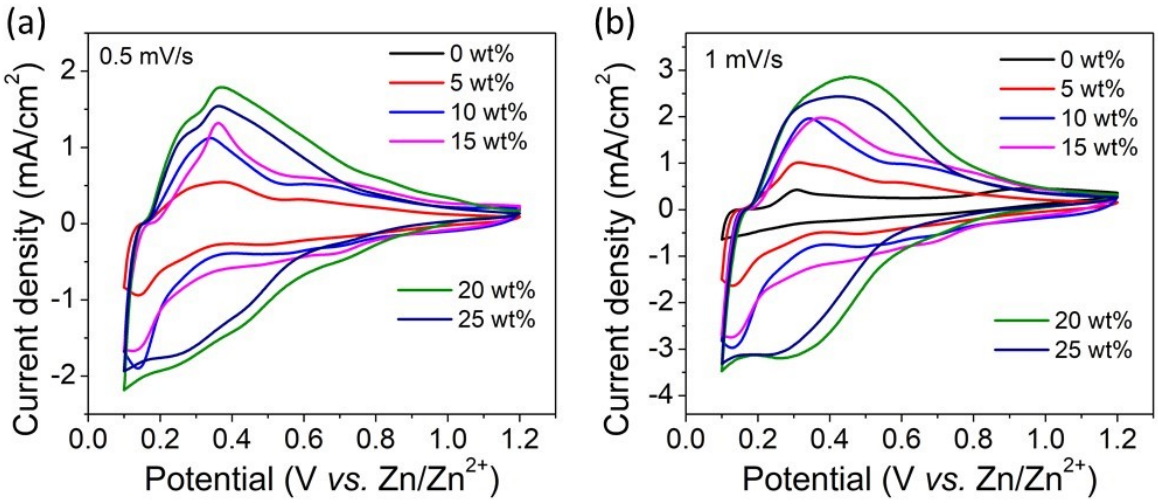

Fig. S5. CV comparison of different wt% of Mo into WO_3 structure at (a) 0.5 mV/s and (b) 1 mV/s.

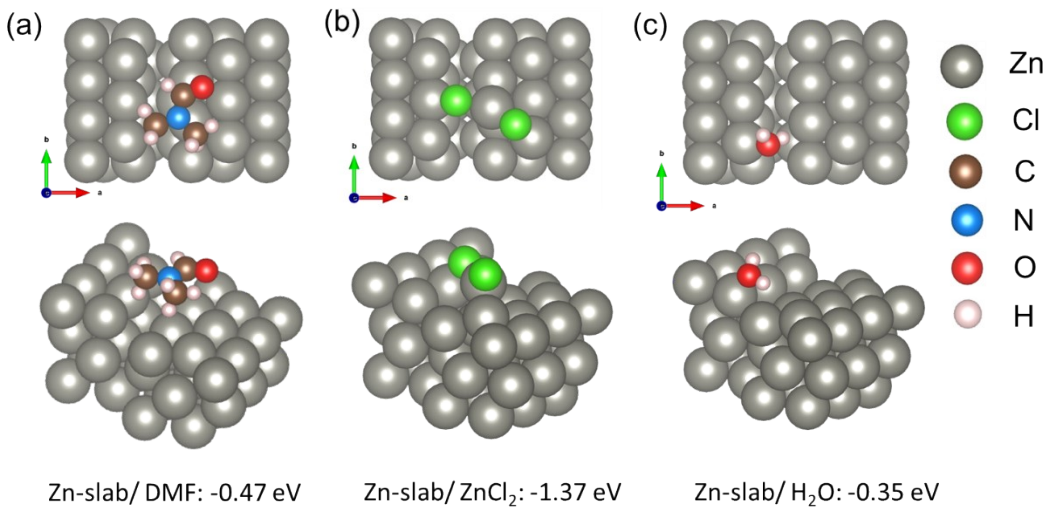

Fig. S6. The calculated adsorption energy of a) DMF molecule, b) $ZnCl_2$, and c) H_2O molecule on a Zn surface.

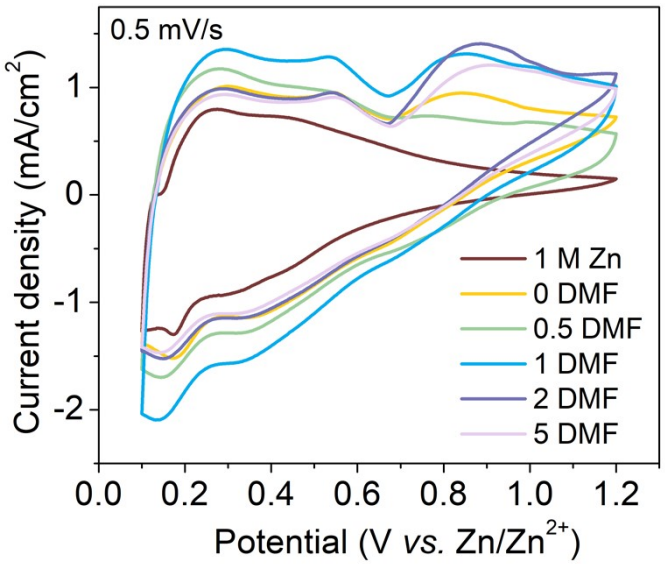

Fig. S7. Cyclic voltammetry of the Mo–WO_3 electrode in WISE electrolytes with varying DMF concentrations.

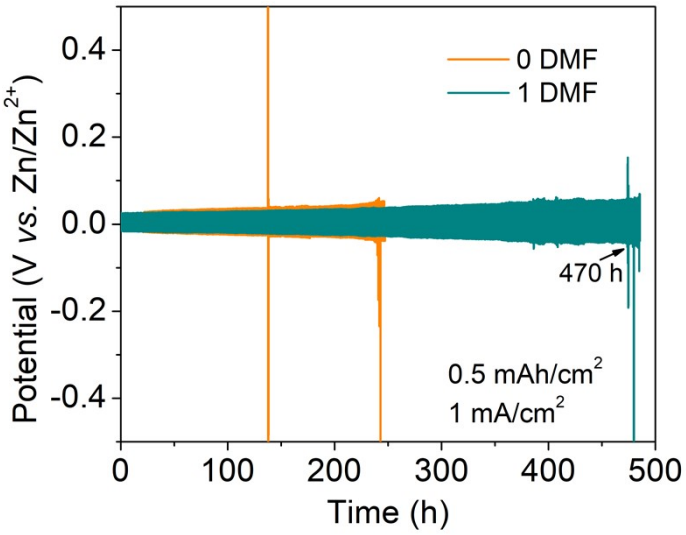

Fig. S8. Comparison of symmetric Z||Zn cell electrochemical behavior in 0 DMF and 1 DMF-containing electrolyte systems.

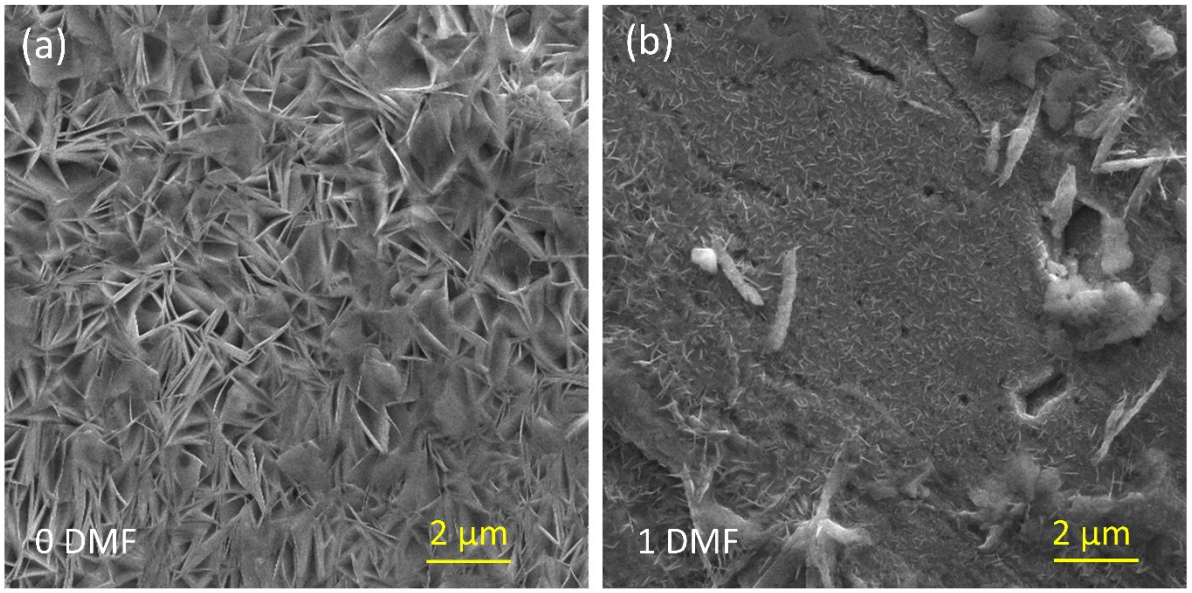

Fig. S9. FESEM images of the zinc foil after cycling in electrolytes containing (a) 0 DMF and (b) 1 DMF.

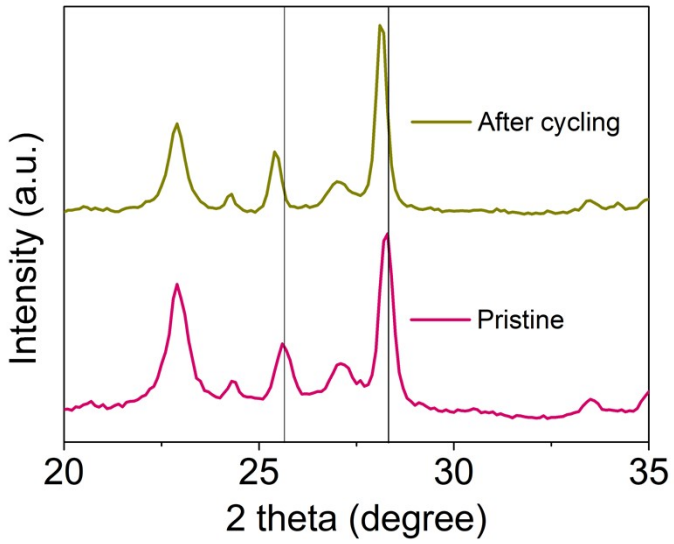

Fig. S10. The XRD pattern of the electrode before and after cycling stability test.

Table S1. XPS Data for WO_3 and Mo-WO_3

Sample	Parameter	$W4f_{7/2}$ (W^{6+})	$W4f_{5/2}$ (W^{6+})	$W4f_{7/2}$ (W^{5+})	$W4f_{5/2}$ (W^{5+})	$W4f_{3/2}$	O1s (O-O)	O1s (-H_2O)	O1s (-OH)
WO_3	Position	35.85	37.97	34.62	36.82	41.72	530.07	530.88	532.43
	Area	127239.7	95429.8	13577.8	10183.3	6421.5	93358.1	38172.1	38246.5
	FWHM	1.33	1.36	0.96	0.8	1.59	1.31	1.32	1.67
Mo-WO_3	Position	35.84	37.92	35.64	37.74	41.85	530.16	531.26	532.42
	Area	70377.3	52783	17943.8	13457.9	18103.1	82060.9	57202.4	55463.1
	FWHM	1.65	1.36	0.93	1.24	1.65	1.45	1.93	2.52

Table S2. Comparison table with other reported literature.

Material	Electrolyte	Capacity	Current density	Cycle number	Reference
Nanoporous WO_3/MoO_3	1 M $LiClO_4$-PC	496 mF/cm^2	0.5 mA/cm^2	5000 cycles at 60% retention	1
WO_3/ZnO	1 M $LiClO_4$-PC	15.24 mF cm−2	1.12 mA/cm^2	NA	2
MnO_2//WO_3	PVA–Na_2SO_4	113 F g^{-1}	5 mV/s	2000 cycles at 85% retention	3
WO_3-MnO_2	Na_2SO_4	103 F g^{-1}	5 mV/s	2500 cycles at 95% retention	4
$WO_3 \cdot 0.33H_2O$	1 M $ZnCl_2$	91 mAh g^{-1}	0.1 A/g	3000 cycles at 94% retention	5
WO_3	$ZnCl_2$ WISE	94.8 mAh g^{-1}	0.1 A/g	1000 cycles at 94.8% retention	6
W/WO_3	2 M $ZnSO_4$	158 mAh g^{-1}	0.1 A/g	1000 cycles	7
Cu-NOW	2 M $ZnSO_4$	160 mAh g^{-1}	0.1 A/g	100 cycles	8
WO_3	0.5 M $(NH_4)_2SO_4$	150 mAh g^{-1}	0.1 A/g	500 cycles	9
$(NH4)_xWO_3$	2 M $ZnSO_4$	153 mAh g^{-1}	0.1 A/g	2200 cycles	10
Mo-WO_3	$ZnCl_2$WI	75 mAh/g	0.1 A/g	3000 cycles at 72%	This Work

	SE-DMF			retention	

References

1 C. C. Wei, P. H. Lin, C. E. Hsu, W. Bin Jian, Y. L. Lin, J. T. Chen, S. Banerjee, C. W. Chu, A. P. Khedulkar, R. A. Doong and K. Tsukagoshi, *Cell Rep Phys Sci*. **2024**, 5, 101836.

2 Z. Bi, X. Li, Y. Chen, X. Xu, S. Zhang and Q. Zhu, *Electrochim Acta*, 2017, 227, 61–68.

3 P. A. Shinde, N. R. Chodankar, V. C. Lokhande, A. M. Patil, T. Ji, J. H. Kim and C. D. Lokhande, *RSC Adv*, 2016, 6, 113442–113451.

4 P. A. Shinde, V. C. Lokhande, A. M. Patil, T. Ji and C. D. Lokhande, *Int J Hydrogen Energy*, 2018, 43, 2869–2880.

5 S. P. Gupta, V. Kotha, P. S. Walke and L. S. Panchakarla, *J Power Sources*. **2024**, 604, 234500.

6 S. Li, Z. Zhang, J. Wu, X. Guo, Y. Chen, C. Wang, F. Yu, Z. Wang, D. Li and Y. Chen, *J Power Sources*. **2023**, 560, 232691.

7 K. Songmueang, D. Zhang, J. Cao, X. Zhang, S. Kheawhom, C. Sriprachuabwong, A. Tuantranont, P. Wangyao and J. Qin, *Chemical Communications*, 2021, 57, 7549–7552.

8 D. Ling, G. Tian, D. Zhang and Q. Wang, *Nano Lett*, 2025, 25, 2684–2692.

9 X. Wen, J. Luo, K. Xiang, W. Zhou, C. Zhang and H. Chen, *Chemical Engineering Journal*, 2022, 458, 141381.

10 G. Tian, Q. Wang, Z. Qu, H. Yu, D. Zhang and Q. Wang, *Small*, 2023, 19, 2206701.