



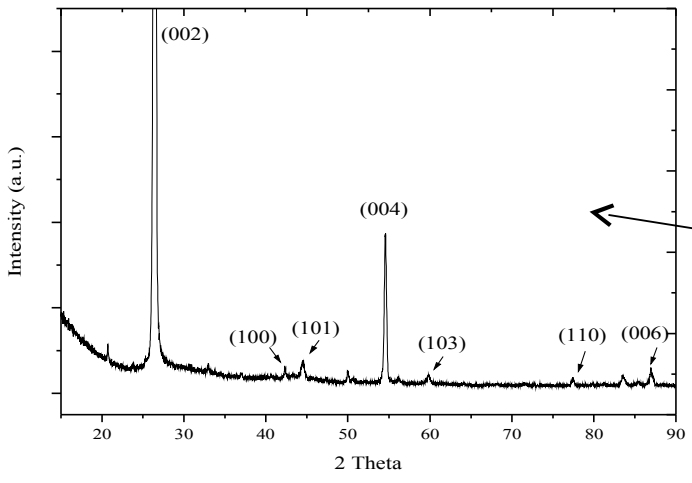
LI-ION BATTERY ANODE USES NANO SIZED SRI LANKA VEIN GRAPHITE TO ENHANCE BATTERY CAPACITY

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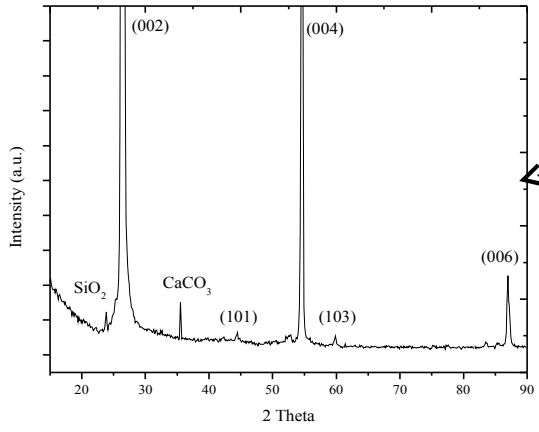
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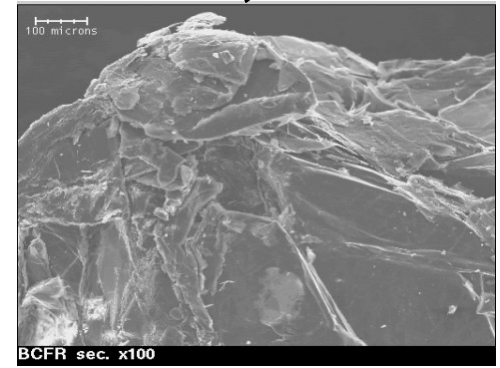
(a)



(b)



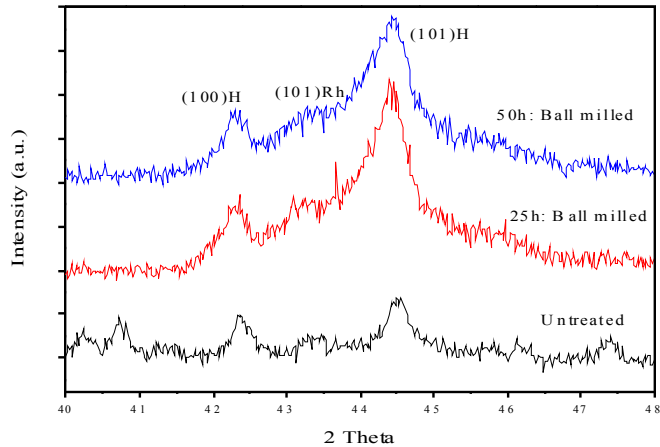
(c)



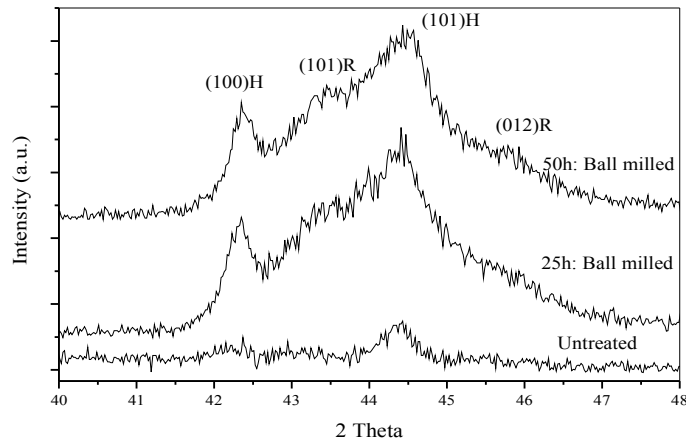
X-ray diffractogram of Bogala coarse flakes of radial graphite (BCFR): (b) X-ray diffractogram of nuclei of BCFR: (c) SEM Photograph of the nuclei.

Variation of the rhombohedral phase contents

$$\frac{(101)_R}{(101)_H} \times 100\%$$

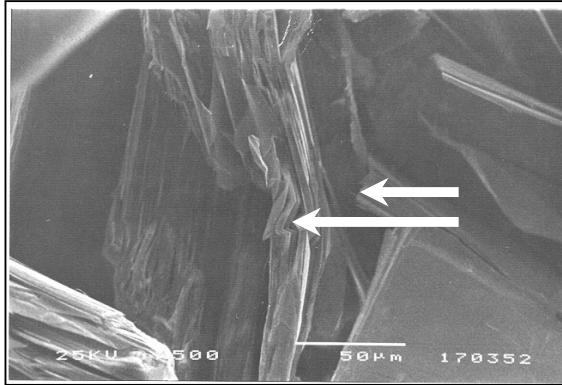


Duration and type of mechanical treatment	L_c (nm)			L_a (nm)		$(101)_R/(101)_H$ intensity ratio %
	d_{002}	d_{004}	d_{006}	d_{110}	d_{100}	
Untreated (63 μ m)	84	65	74	152	141	14
After 25 hrs. sieve-shaken (63 μ m)	61	47	45	125	95	22
After 50 hrs. sieve-shaken (63 μ m)	57	52	50	122	84	30
After 25 hrs. ball-milled	48	36	39	88	82	44
After 50 hrs. ball-milled	45	36	38	60	89	48

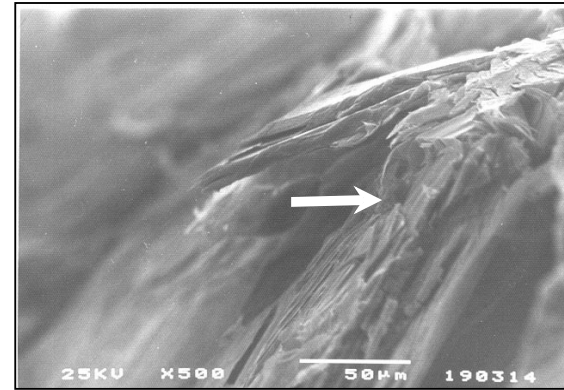


Duration and type of mechanical treatment	L_c (nm)			L_a (nm)		$(101)_R/(101)_H$ intensity ratio %
	d_{002}	d_{004}	d_{006}	d_{110}	d_{100}	
Untreated (63 μ m)	63	53	65	NA	96	21
After 25 hrs. sieve-shaken (63 μ m)	68	58	50	90	164	26
After 50 hrs. sieve-shaken (63 μ m)	65	61	76	136	160	22
After 25 hrs. ball-milled	38	32	38	89	67	52
After 50 hrs. ball-milled	44	30	32	120	88	67

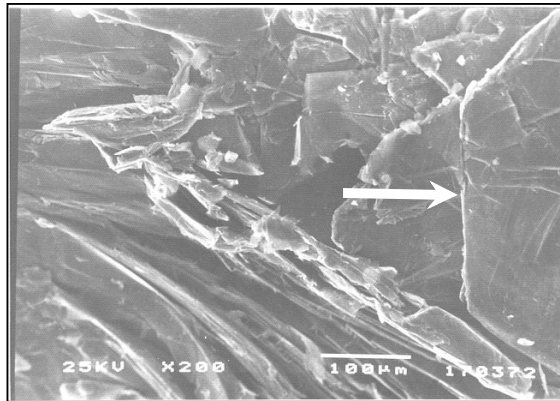
Microstructure



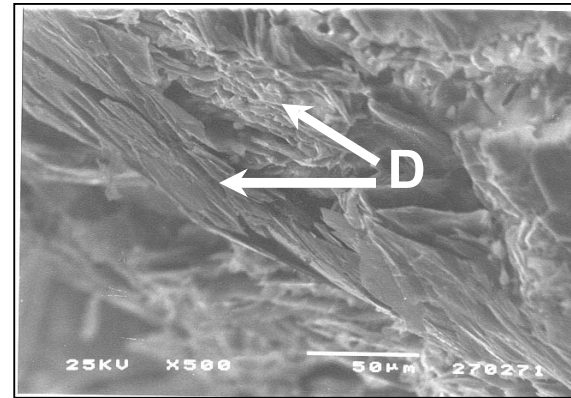
(a)



(b)



(c)



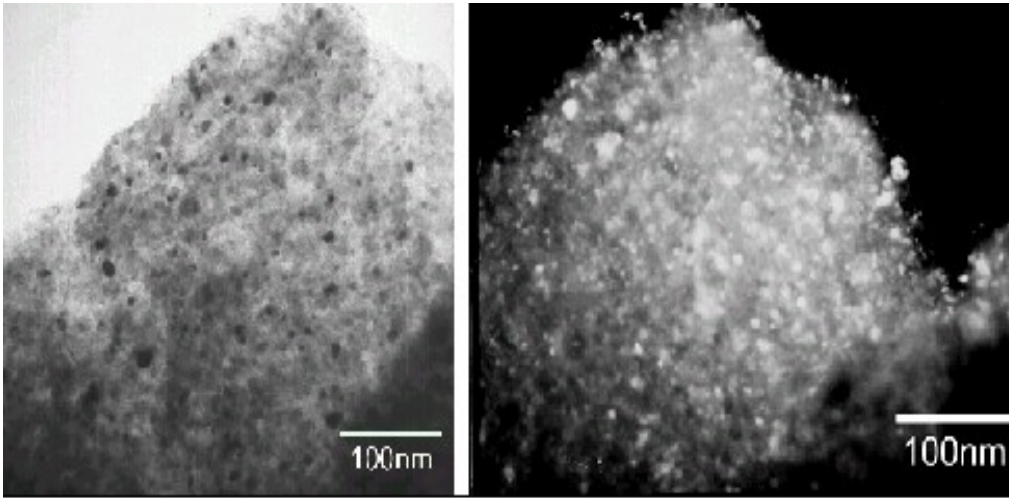
(d)

(a) partly hexagonal crystal faces and random tacking defects of Kahatagaha/Kolongaha shiny slippery fibrous graphite,

(b) partly hexagonal crystal faces and random tacking defects of Bogala shiny slippery fibrous graphite, (

(c) compact equigranular aggregates of hexagonal crystal faces of Kahatagaha/Kolongaha coarse flakes of radial graphite and

(d) crystallized needles of Bogala shiny slippery fibrous graphite.

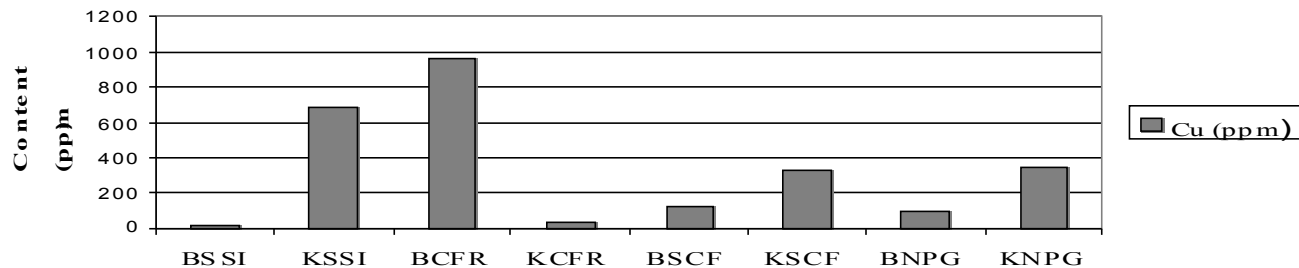
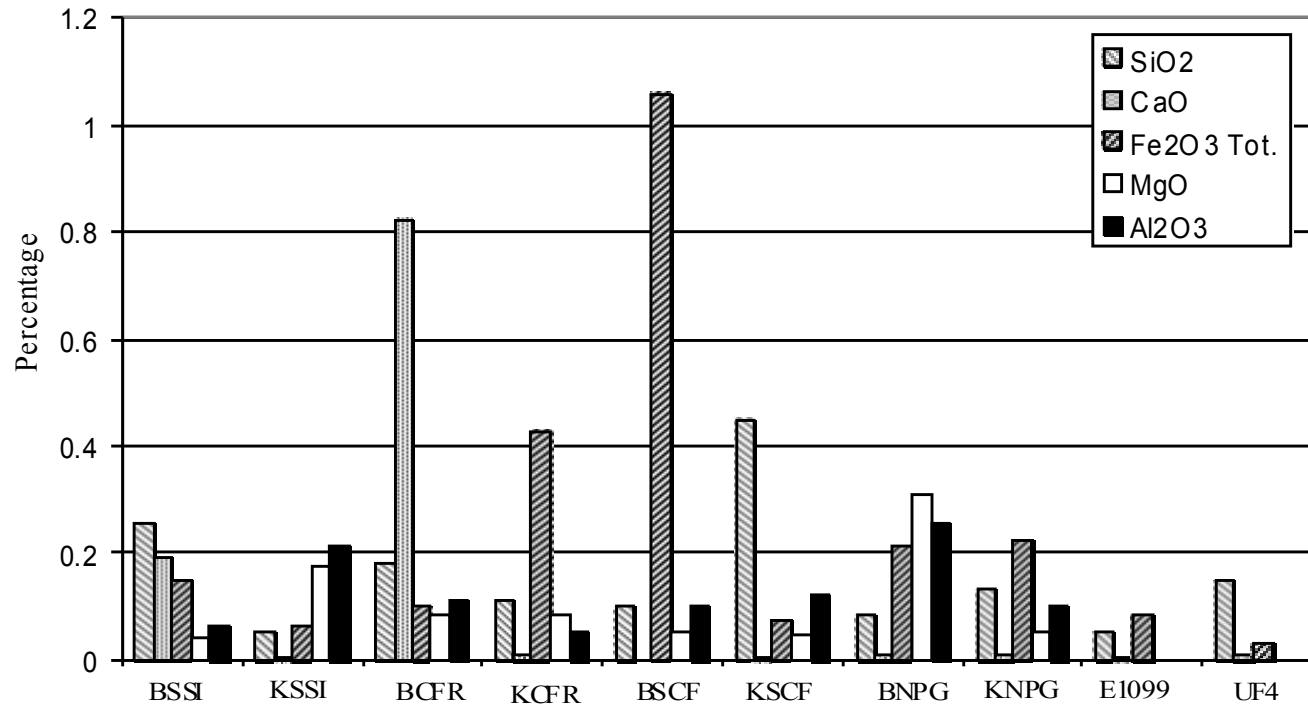


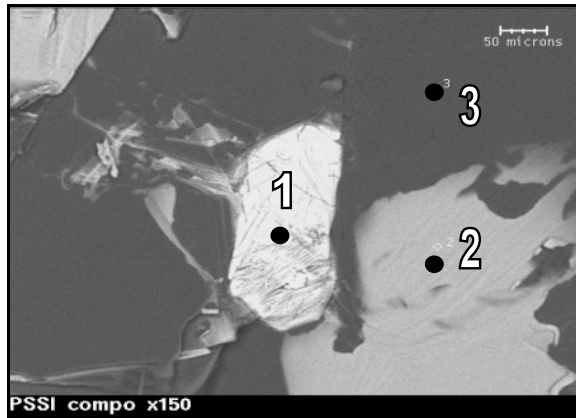
TEM image of KSSI graphite during 50 hrs.

Location	Sample no.	Graphite morphology	Carbon %	Sulfur %	C _{ave.} %	S _{ave.} %
Bogala mine	1	Shiny Slippery fibrous graphite (BSSI)	97.796 98.610	0.026 0.002	98.20	0.01
Kahatagaha / Kolongaha mine	1	Shiny Slippery fibrous graphite (KSSI)	99.558 98.840	0.011 0.011	99.12	0.01

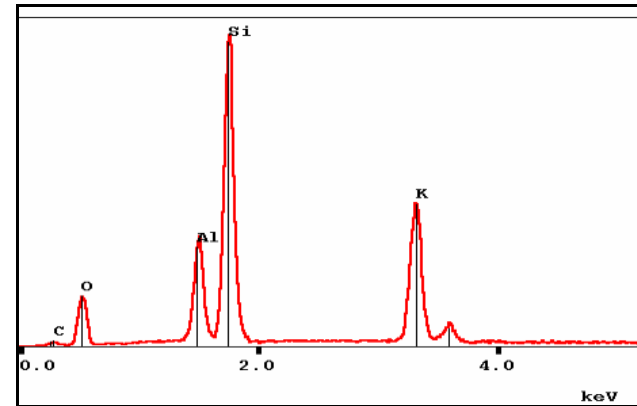
Carbon content measured by Carbon-Sulfur determination method

Impurity contents of vein graphite

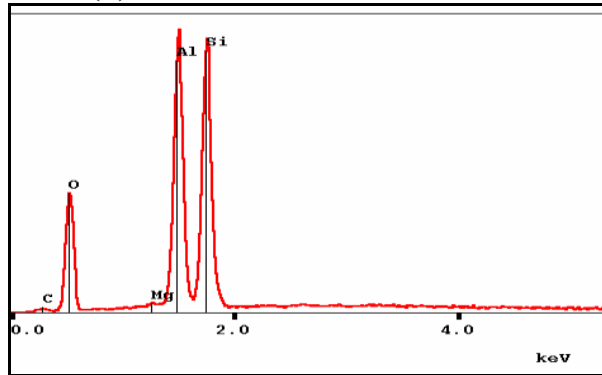




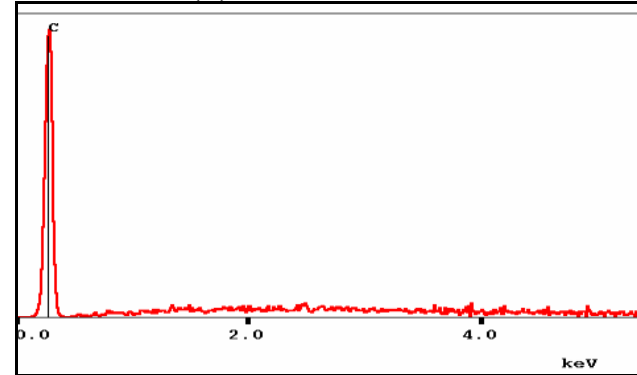
(a)



(b)



(c)

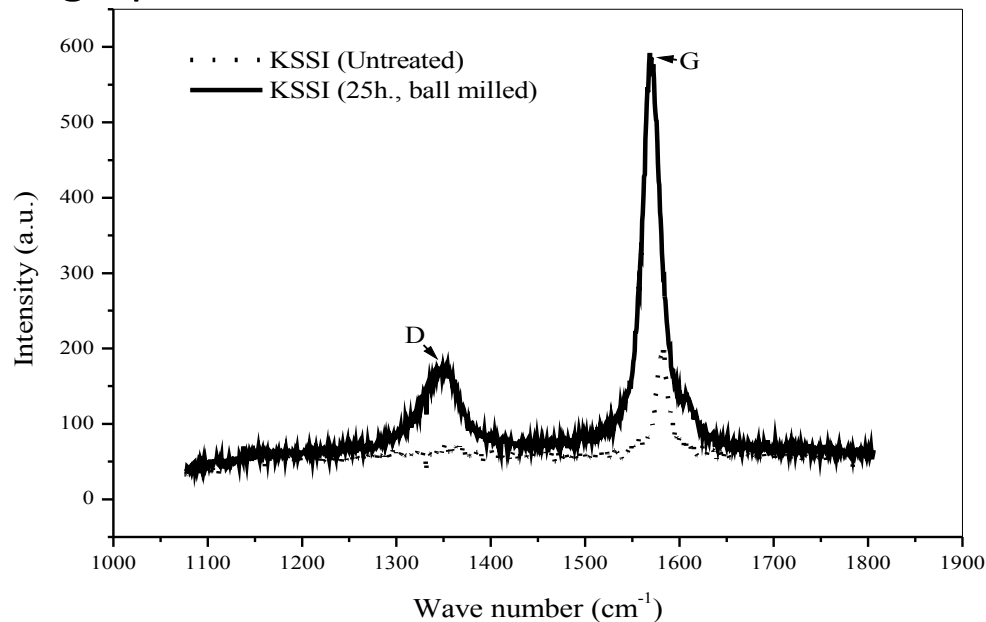


(d)

✓ Energy Dispersive X-ray (EDX) analysis is one of the versatile techniques available for the investigation of the distribution of the materials.

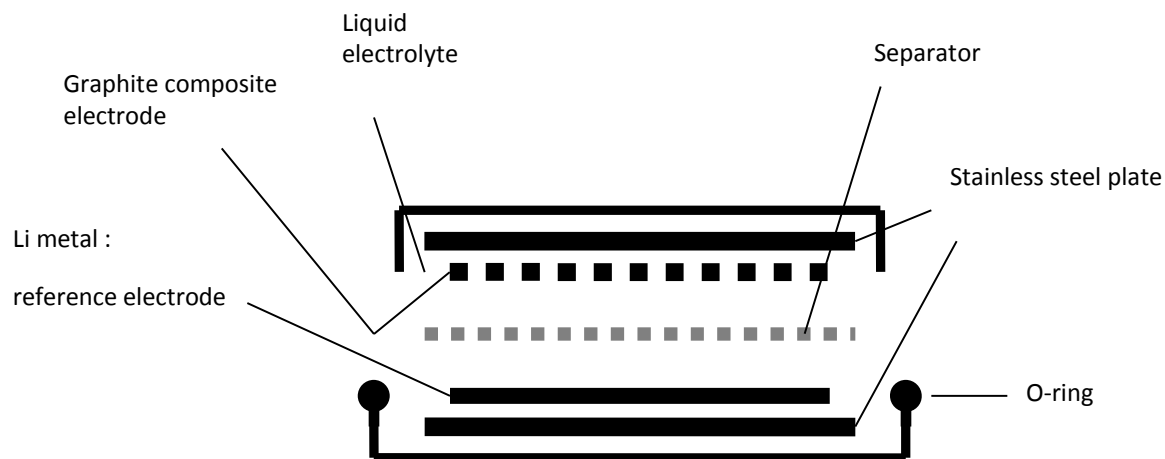
✓ EDX analysis was performed on a JSM 6400 scanning electron microscope equipped with an Energy Dispersive Microanalyser to identify the materials in the samples.

Evolution of Raman spectra of untreated and ball-milled natural vein graphite



- ✓ Raman spectrometry is a unique tool to characterize structure defects in graphite and gives complementary information to XRD.
- ✓ In graphite there are two main Raman active modes in first order. The G-mode appears at 1580-1585 cm⁻¹ and D-mode at 1350 cm⁻¹.
- ✓ The second order Raman mode appears at 2725 cm⁻¹. The G-mode is associated with C-C plane bond stretching (E_{2g} mode) while the D-mode is attributed to the finite size effect.

Li/graphite cell assemble

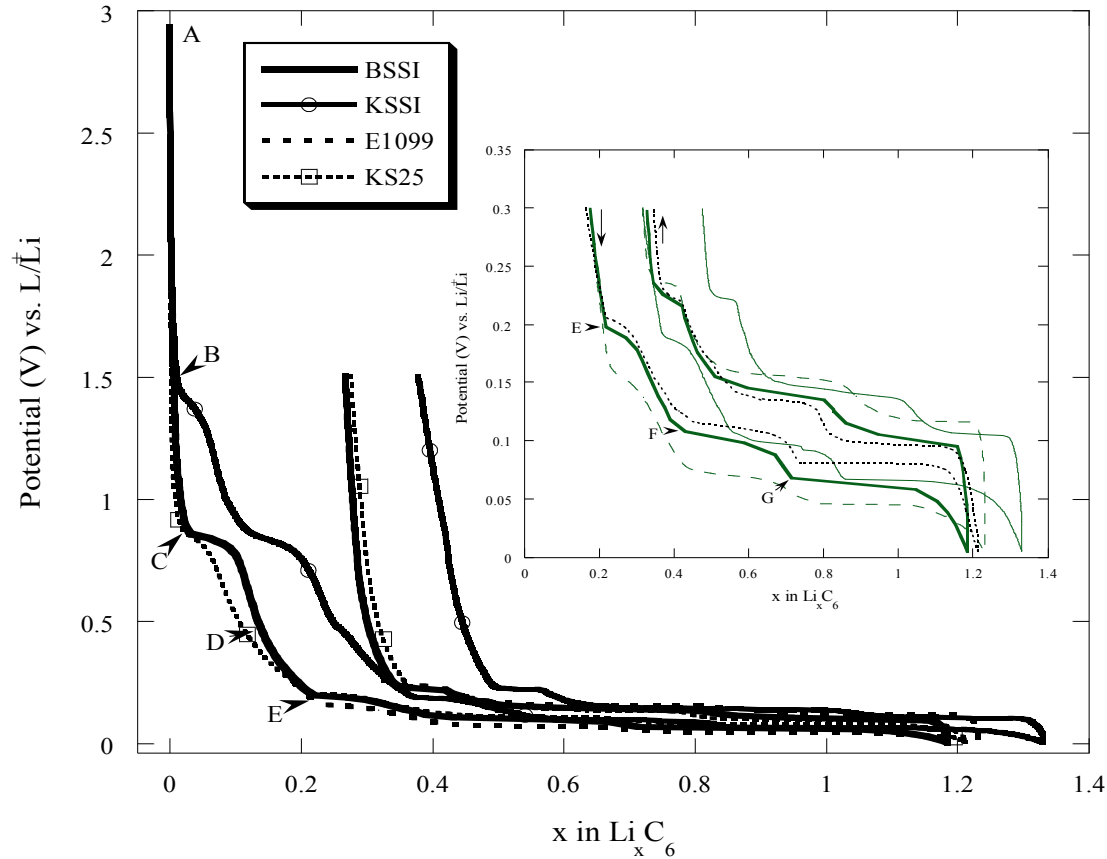


Then coin type cells (CR2430): metallic lithium counter electrode and composite membrane as the working electrode

Separator: A micro-porous polypropylene sheet (Celgard 2400)

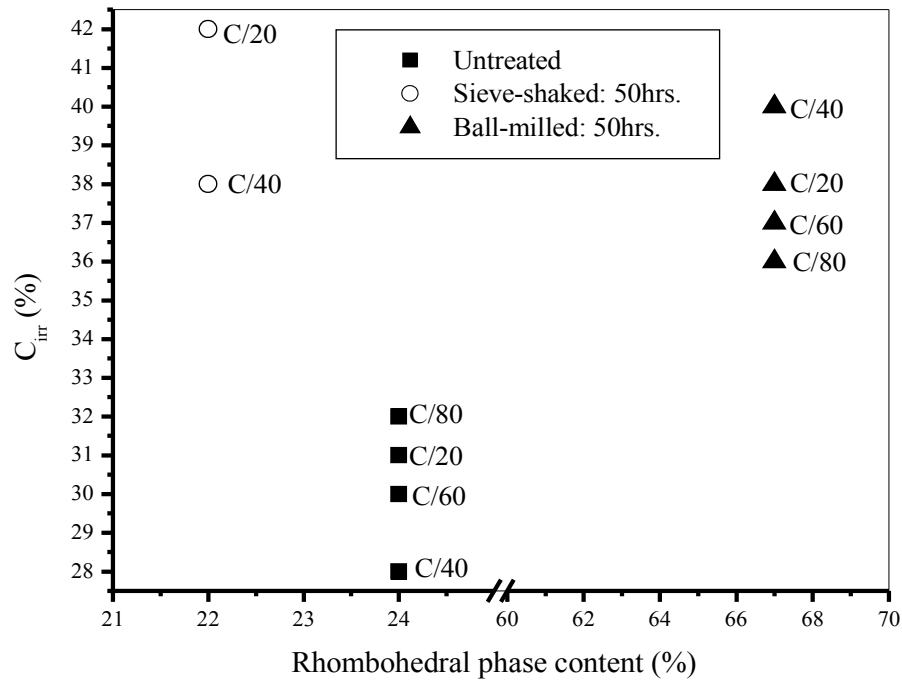
Electrolytes: 1M LiPF_6 and 1M LiClO_4 in EC/ DMC (1:1)

Electrochemical experiments were performed with a MacPile multichannel potentiostat-galvanostat (Biologic, France).

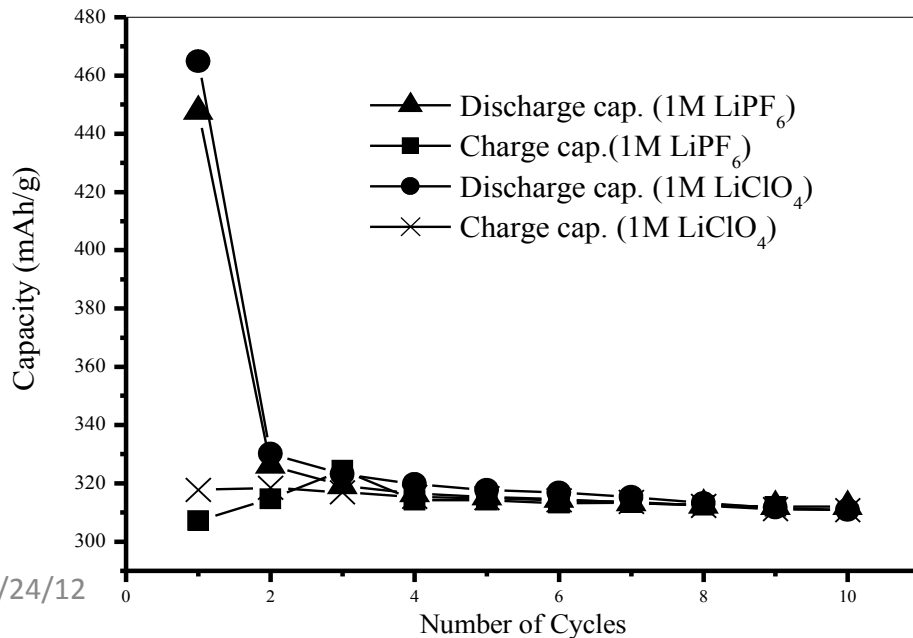


a) First discharge-charge curve for Li/graphite (KSSI) cell for different electrolytes with a current rate C/20, at 25 °C,

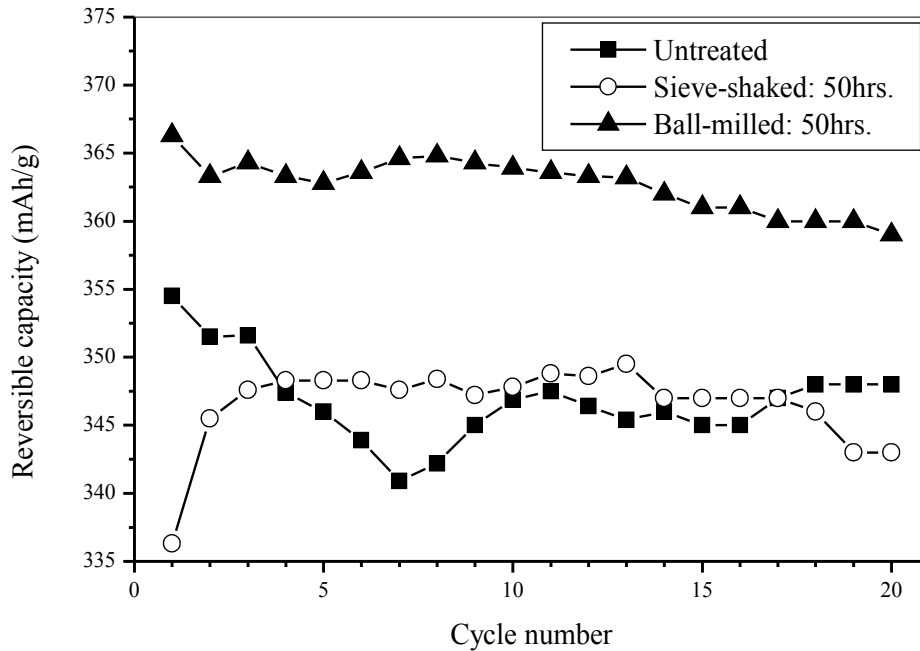
(b) Li/ natural graphite (Sri Lanka and Madagascar) and synthetic graphite (KS25) cells in 1M LiPF_6 (EC/DMC), at current rate C/40.



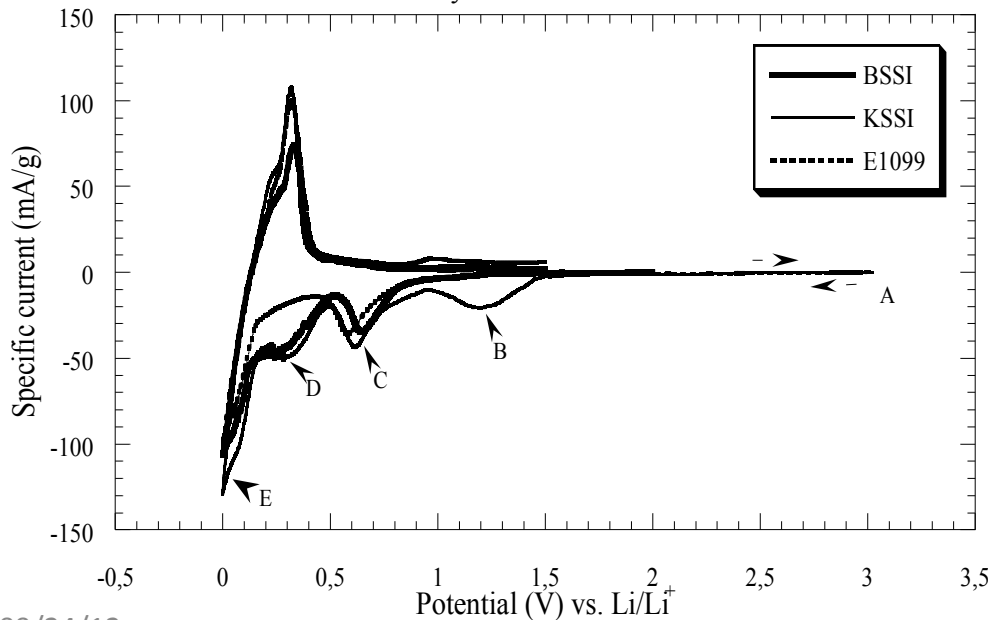
Variation of the irreversible capacity loss in relation with the rhombohedral phase content for untreated and treated KSSI graphite at different current rates in 1M LiPF_6 (EC/DMC).



Relationship between the charge and discharge capacity as a function of the cycle number.



Variation of the reversible capacity as a function of the different cycles for untreated and treated KSSI graphite at a C/40 current rate within 1M LiPF₆ (EC/DMC).



cyclic voltammogram of Li/graphite (Sri Lanka and Madagascar) cells

Duration and type of mechanical treatment	Current rate								$(101)_R/(101)_H$ intensity ratio %
	C/20		C/40		C/60		C/80		
	C_{rev} (mAh/g)	C_{irr} %	C_{rev} (mAh/g)	C_{irr} %	C_{rev} (mAh/g)	C_{irr} %	C_{rev} (mAh/g)	C_{irr} %	
Untreated (63 μ m)	301	46	341	23	266	64	345	54	14
After 50hrs. ball-milled	334	43	362	35	358	34	354	37	48
After oxidative treatment in air	359	17	391	13	398	4	396	8	21
After oxidative treatment in $(NH_4)_2S_2O_8$	371	9	387	12	394	6	396	10	18

Duration and type of mechanical treatment	Current rate								$(101)_R/(101)_H$ intensity ratio %
	C/20		C/40		C/60		C/80		
	C_{rev} (mAh/g)	C_{irr} %	C_{rev} (mAh/g)	C_{irr} %	C_{rev} (mAh/g)	C_{irr} %	C_{rev} (mAh/g)	C_{irr} %	
Untreated (63 μ m)	307	31	354	28	300	30	355	32	24
After 50hrs. ball-milled	369	38	366	40	365	37	370	36	67
After oxidative treatment in air	369	18	397	16	399	6	379	25	21
After oxidative treatment in $(NH_4)_2S_2O_8$	365	10	398	7	396	18	389	11	20

First reversible and irreversible capacities of treated and untreated (a) BSSI and (b) KSSI graphite

Conclusions

The present study confirms that Sri Lankan natural graphite is promising as intercalation anode material in rechargeable lithium battery applications due its unique morphology, low cost and high purity.

The electrochemical properties of nano sized BSSI and KSSI graphite can further be enhanced by simple ball-milling or chemical treatments, which can be used for value addition to Sri Lanka graphite.

Future Plan

- ❑ Purification of graphite: using flotation and mechanical processing methods and chemical treatments.
- ❑ Electrochemical and other industrial applications
- ❑ New technological applications