Article:
Thornby, J, Verma, D, Cochrane, R et al. (4 more authors) (2019) Indentation-based characterization of creep and hardness behavior of magnesium carbon nanotube nanocomposites at room temperature. SN Applied Sciences, 1 (7). ARTN: 695. ISSN 2523-3963

https://doi.org/10.1007/s42452-019-0696-9

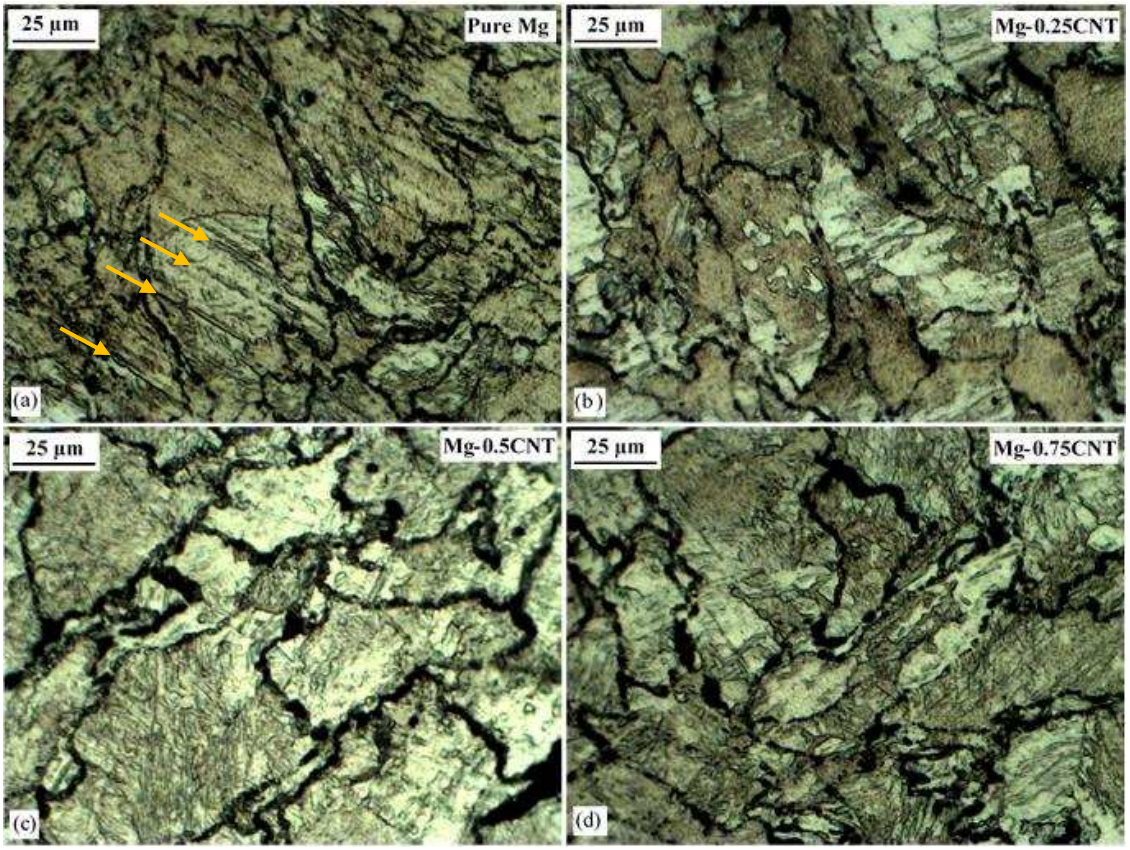


Figure 1. Optical micrographs revealing the cross-sectional grain morphologies of (a) Pure Mg, (b) Mg-0.25 v/v % CNT, (c) Mg-0.5 v/v % CNT, and (d) Mg-0.75 v/v % CNT. Arrows are added to (a) to show the mechanical twins present in pure Mg.

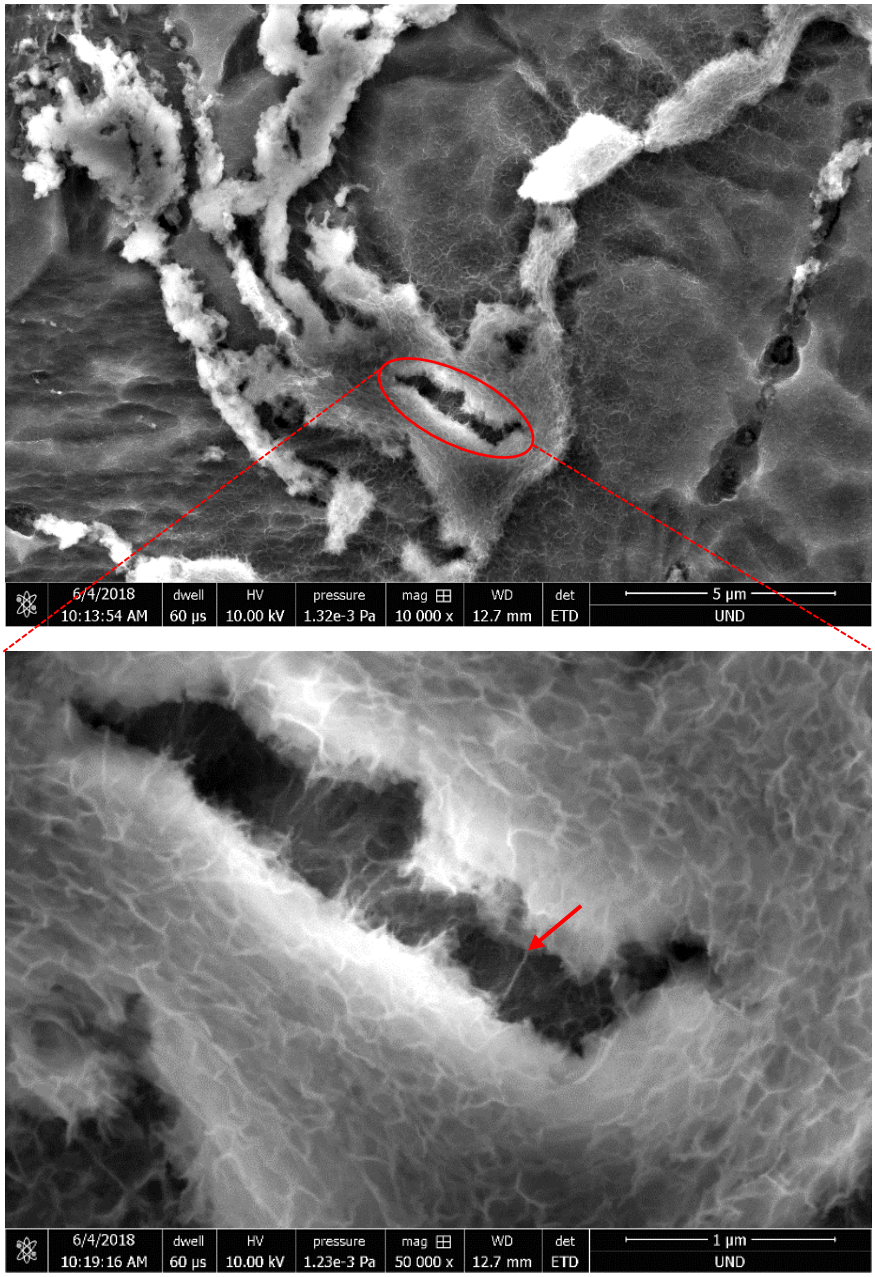
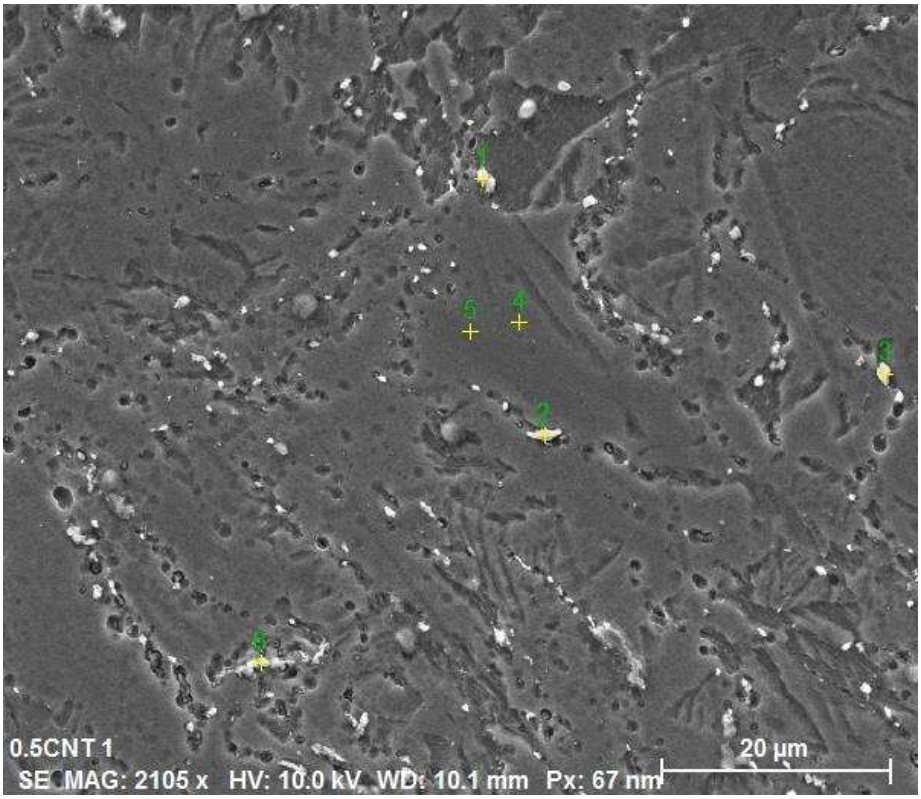


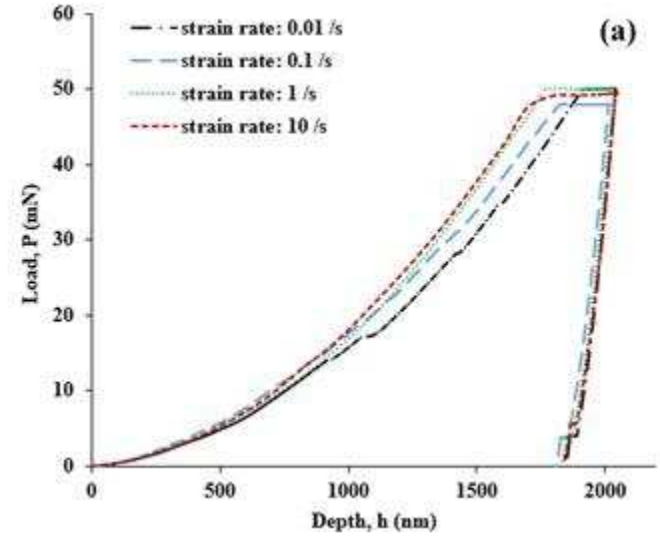
Figure 2. Scanning Electron Microscopy (SEM) images of Mg-0.5 v/v % CNT.
The higher-magnification image reveals an individual CNT fiber, indicated with an arrow.

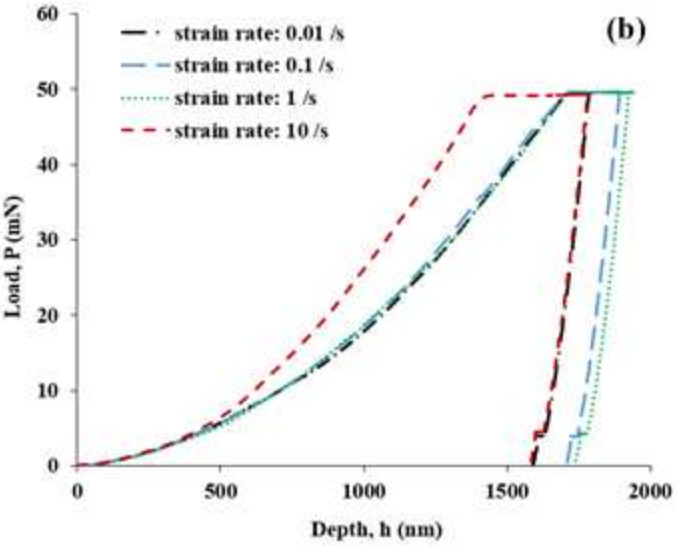


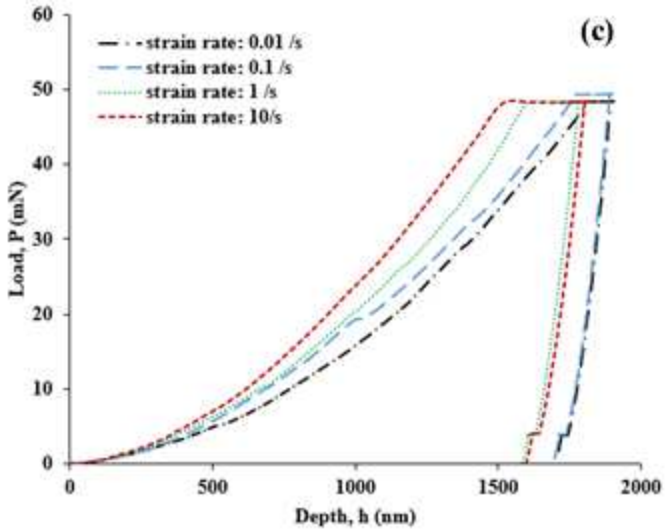
Norm. mass percent (%)

Spectrum	C	O	Mg
1	-	43.34	56.66
2	-	39.19	60.81
3	8.46	41.82	49.72
4	-	-	100.00
5	-	-	100.00
6	4.28	17.78	77.94

Figure 3. Energy dispersive X-ray spectroscopy (EDS) performed on Mg-0.5 v/v % CNT sample for confirmation of sample composition.


(a)
strain rate: 0.01 /s
strain rate: 0.1 /s
strain rate: 1 /s
strain rate: 10 /s
Load, P (mN)
Depth, h (nm)
0
10
20
30
40
50
60
0
500
1000
1500
2000


(b)
strain rate: 0.01 /s
strain rate: 0.1 /s
strain rate: 1 /s
strain rate: 10 /s
Load, P (mN)
Depth, h (nm)
0
10
20
30
40
50
60
0
500
1000
1500
2000


(c)
strain rate: 0.01 /s
strain rate: 0.1 /s
strain rate: 1 /s
strain rate: 10/s
Load, P (mN)
Depth, h (nm)
0
10
20
30
40
50
60
0
500
1000
1500
2000

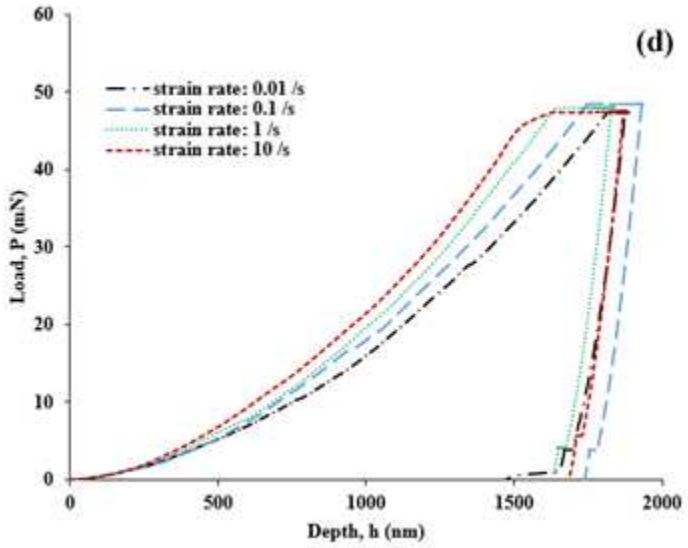
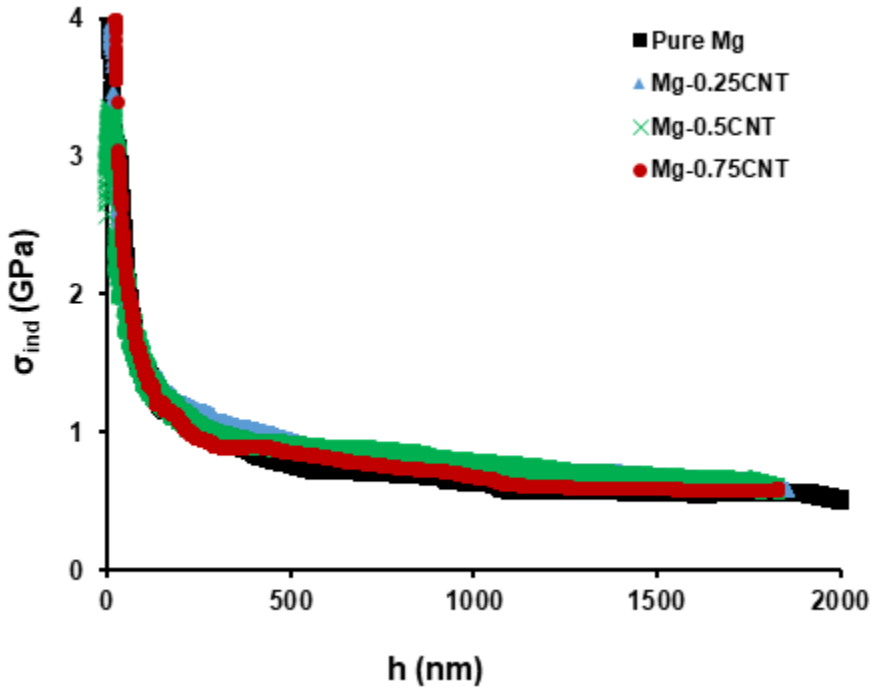
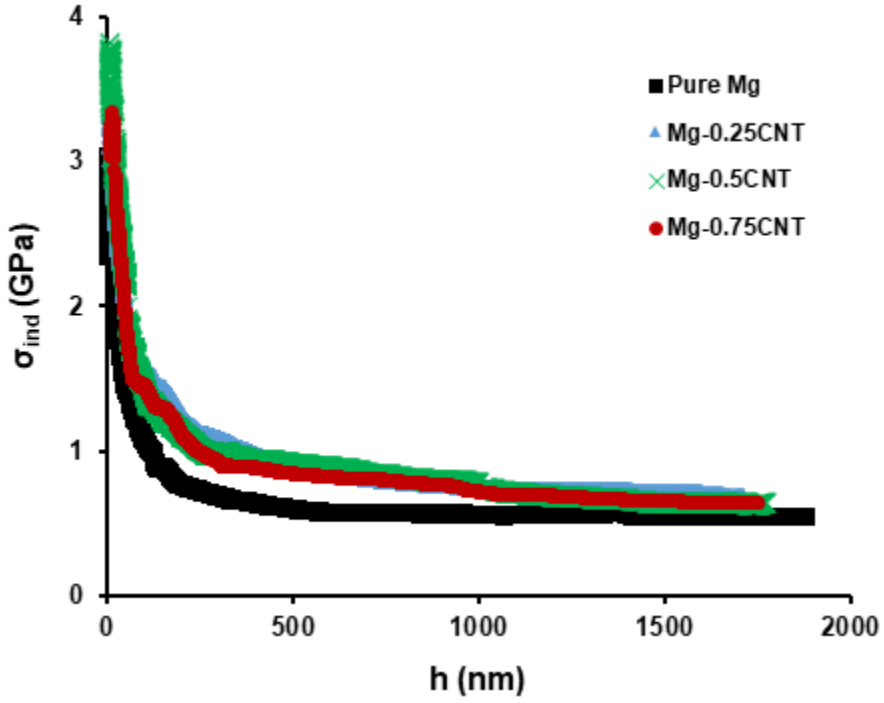


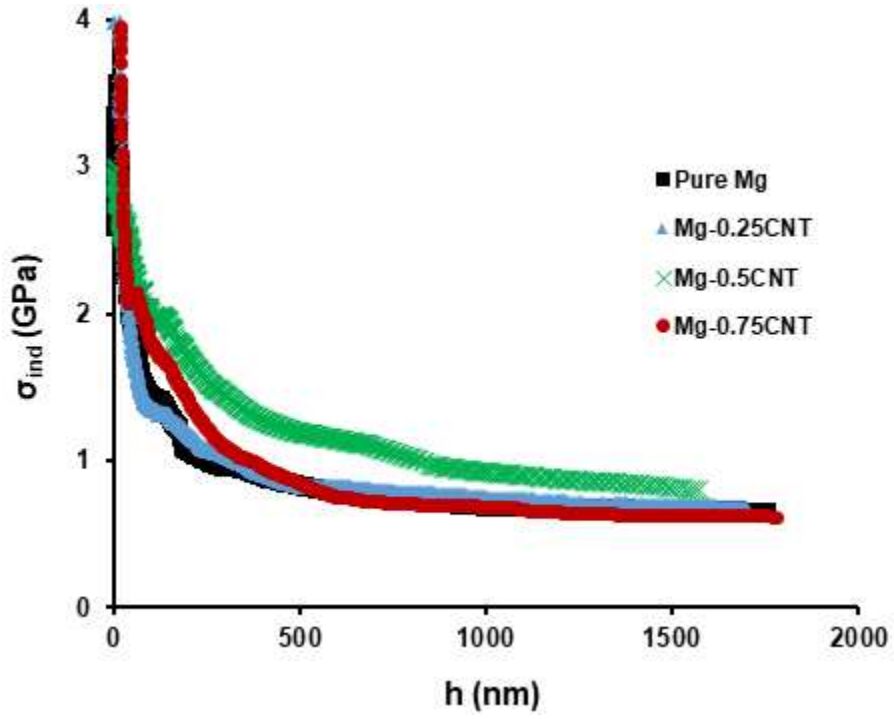
Figure 4. Load–displacement curves displaying loading, holding, and unloading portions at different strain rates (0.01-10 /s) for: (a) Pure Mg, (b) Mg–0.25 vol. % CNT, (c) Mg–0.5 vol. % CNT, and (d) Mg–0.75 vol. % CNT.
Mg: magnesium; CNT: carbon nanotube.


Pure Mg
Mg-0.25CNT
Mg-0.5CNT
Mg-0.75CNT
σind (GPa)
h (nm)
0
1
2
3
4
0
500
1000
1500
2000

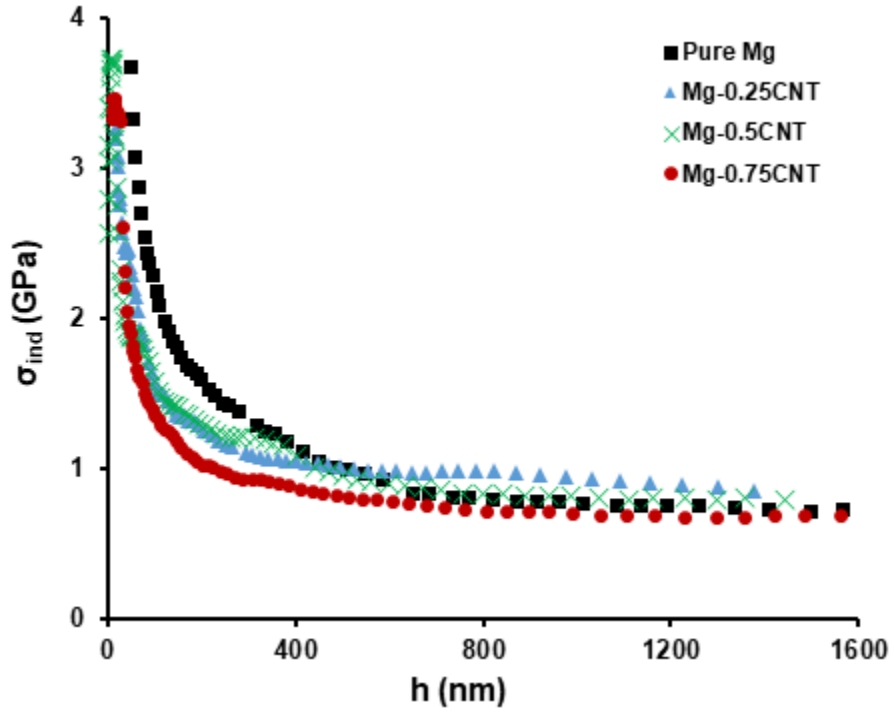
a


Pure Mg
Mg-0.25CNT
Mg-0.5CNT
Mg-0.75CNT
σind (GPa)
h (nm)
0
1
2
3
4
0
500
1000
1500
2000

b



c



d

Figure 5. Indentation stress versus displacement curve for the strain rate of: (a) 0.01 /s, (b) 0.1 /s, (c) 1.0 /s, and (d) 10 /s. The Indentation Size Effect (ISE) phenomenon is observed in all tests. Mg: Magnesium; CNT: carbon nanotube; ISE: indentation size effect.

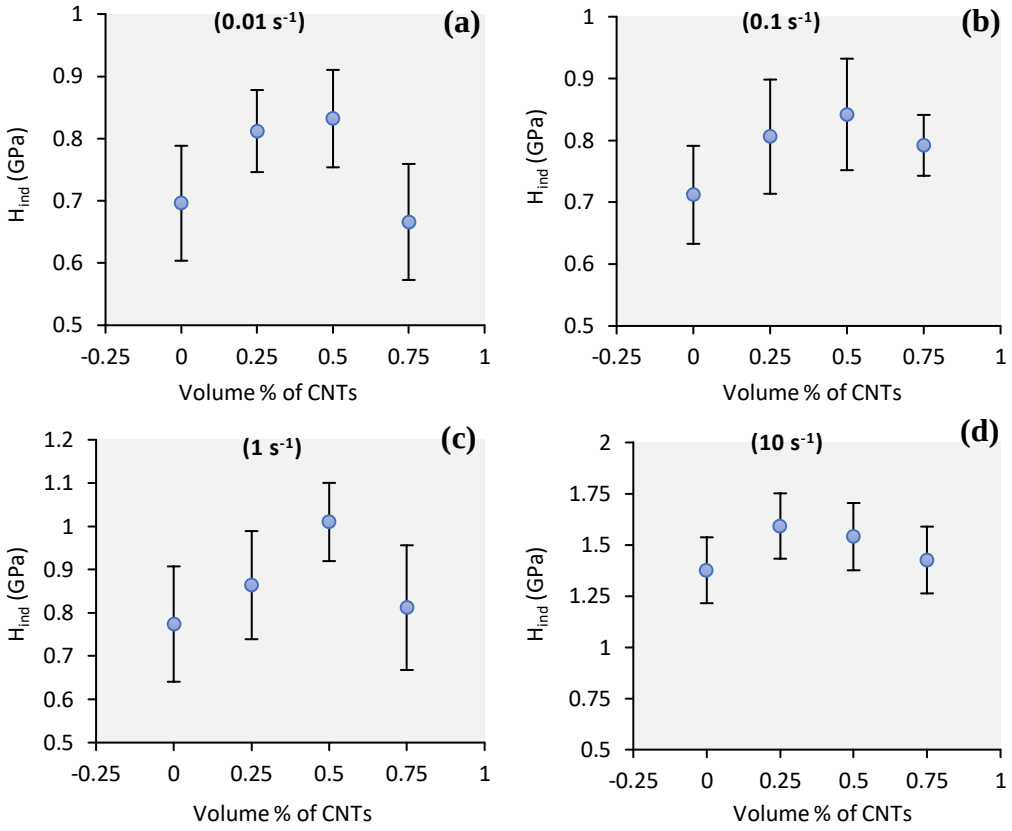
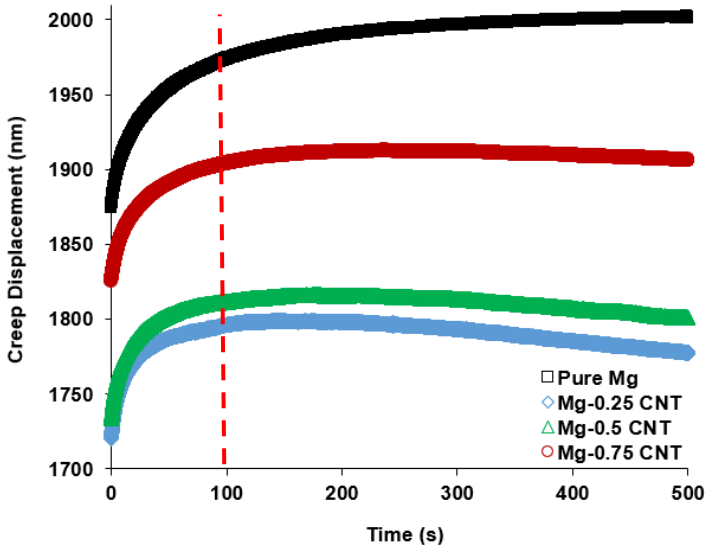
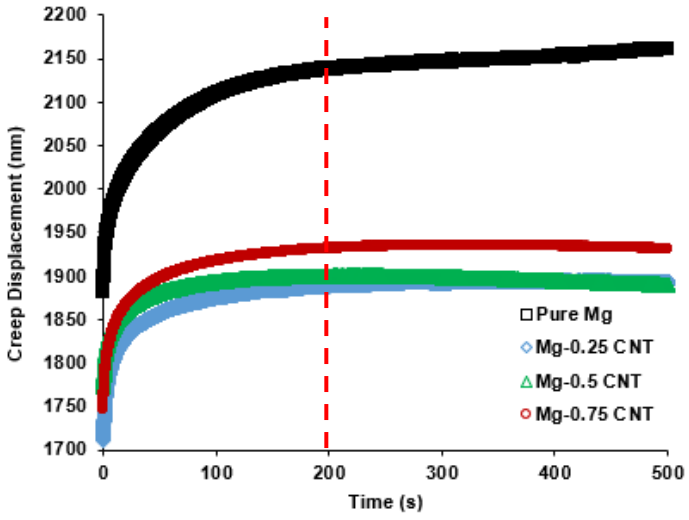


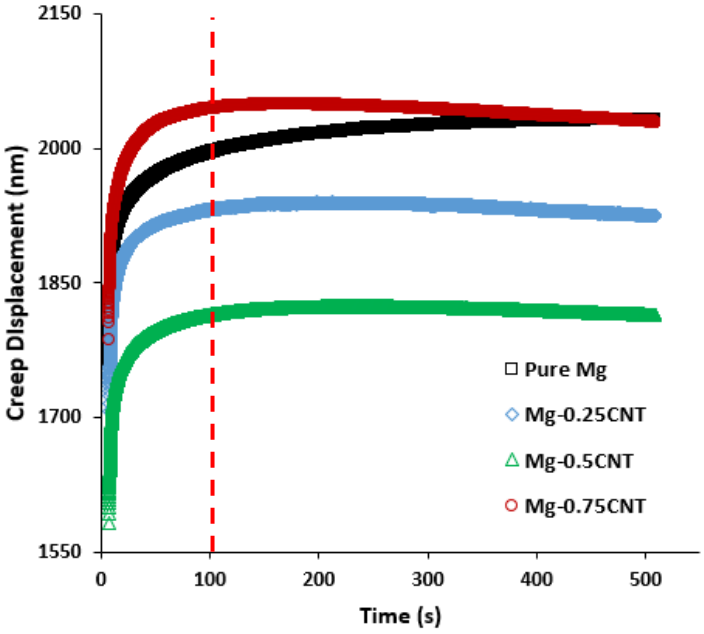
Figure 6. Variation of indentation hardness as a function of CNT loading over four strain rates: (a) 0.01 s^{-1}, (b) 0.1 s^{-1}, (c), 1 s^{-1}, and (d) 10 s^{-1}.


Creep Displacement (nm)
2000
1950
1900
1850
1800
1750
1700
0
100
200
300
400
500
Time (s)
Pure Mg
Mg-0.25 CNT
Mg-0.5 CNT
Mg-0.75 CNT

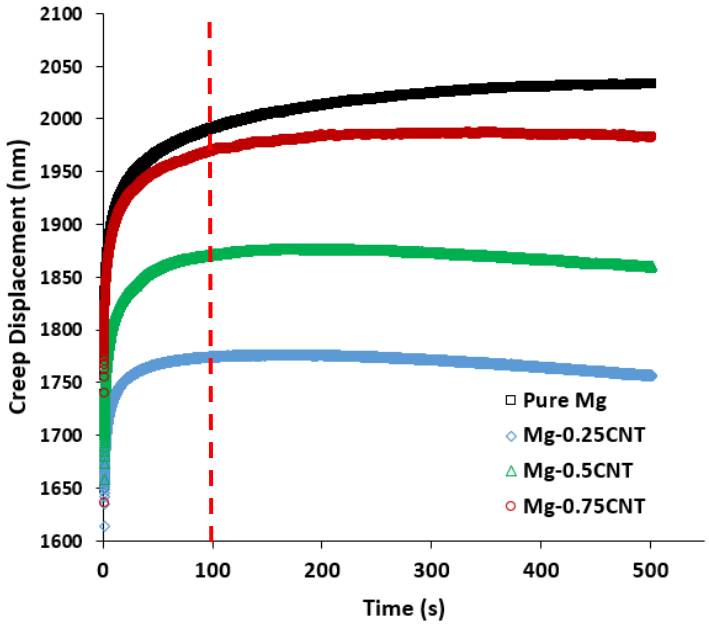
a


Creep Displacement (nm)
2200
2150
2100
2050
2000
1950
1900
1850
1800
1750
1700
0
100
200
300
400
500
Time (s)
Pure Mg
Mg-0.25 CNT
Mg-0.5 CNT
Mg-0.75 CNT

b

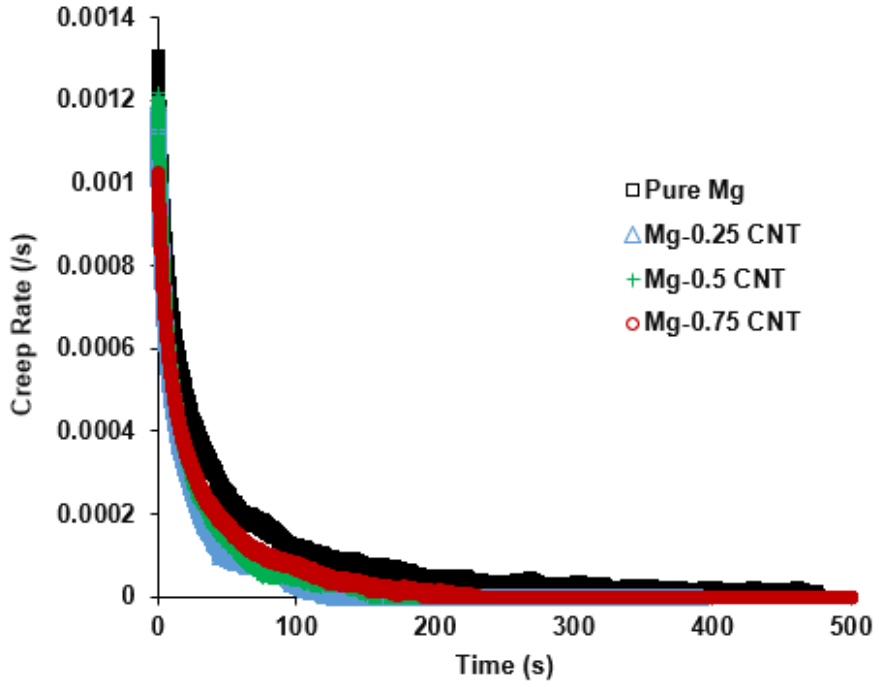


c

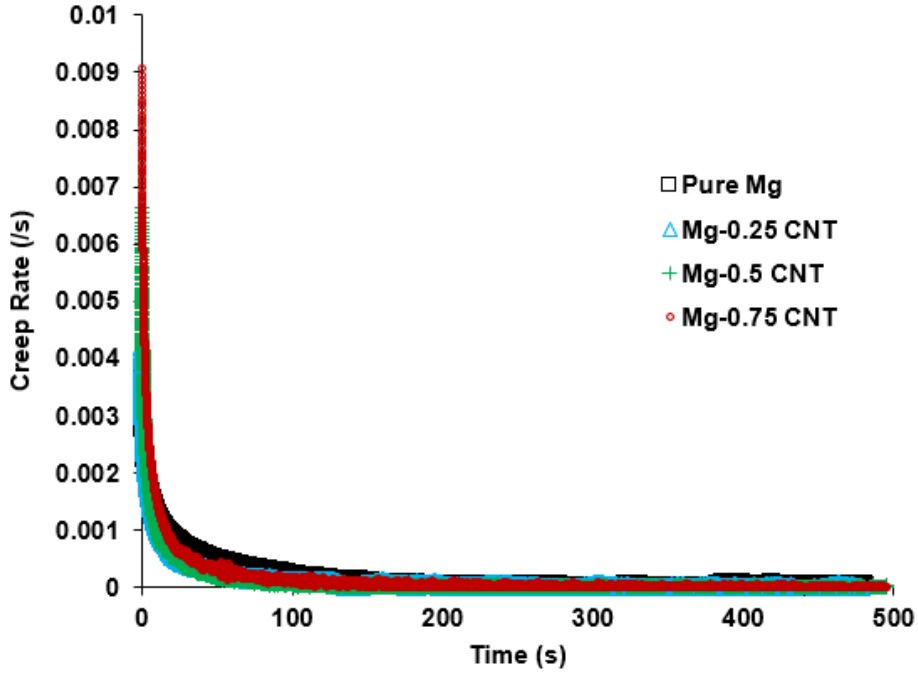


d

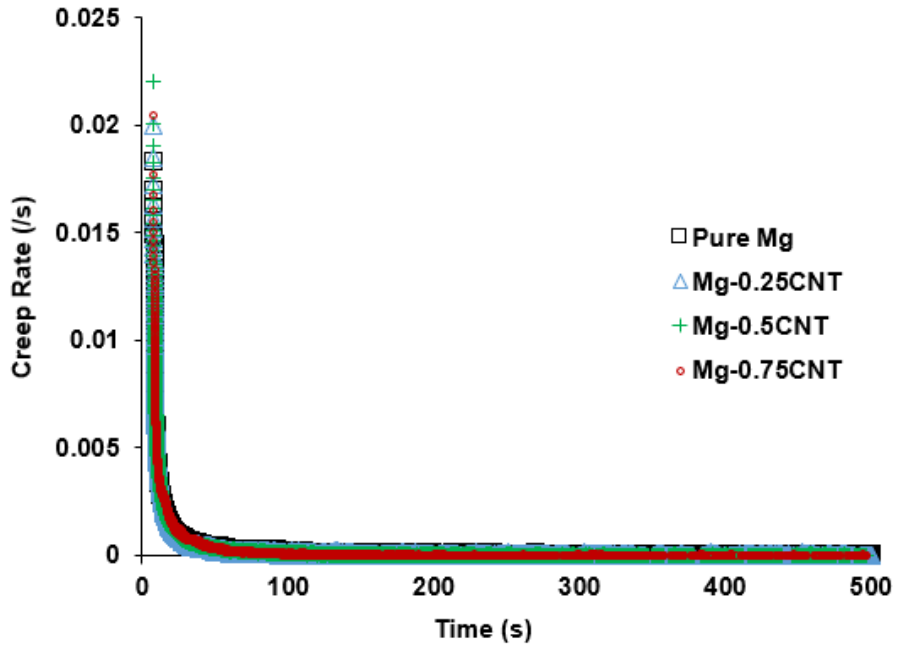
Figure 7. Creep displacement and creep rate versus hold time (500s) for pure Mg and Mg-CNT nanocomposites at four distinct strain rates: (a) 0.01 /s, (b) 0.1 /s, (c) 1.0 /s, and (d) 10 /s. Transient and steady-state creep are observed in all curves. Mg: Magnesium; CNT: carbon nanotube.


0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
Creep Rate (/s)
0
100
200
300
400
500
Time (s)
Pure Mg
Mg-0.25 CNT
Mg-0.5 CNT
Mg-0.75 CNT

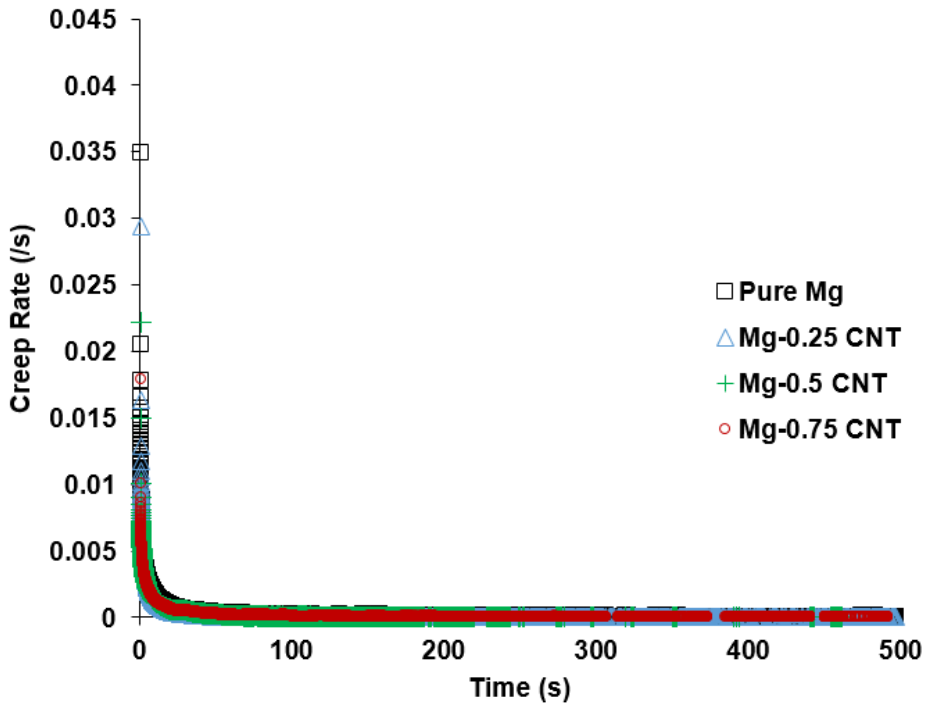
a


0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Creep Rate (/s)
0
100
200
300
400
500
Time (s)
Pure Mg
Mg-0.25 CNT
Mg-0.5 CNT
Mg-0.75 CNT

b



c



d

Figure 8. Creep rate versus hold time (500s) for all four samples at the four strain rates: (a) 0.01 /s, (b) 0.1 /s, (c), 1.0 /s, and (d) 10 /s.

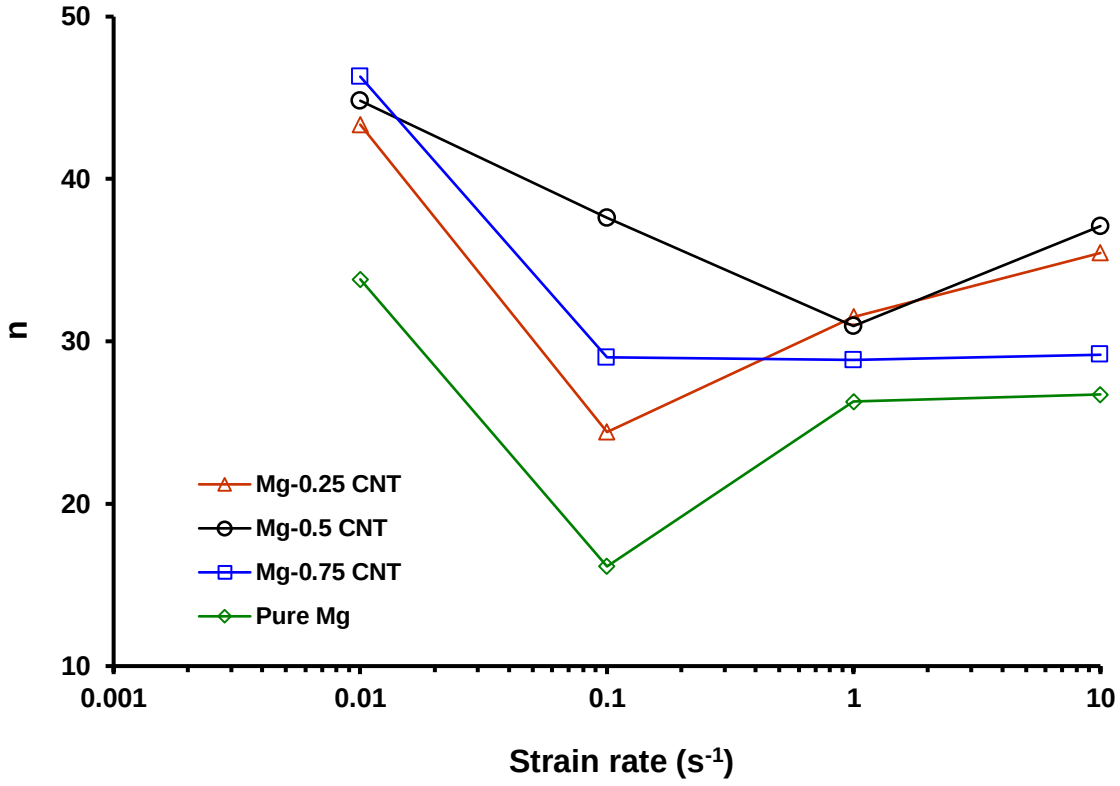


Figure 9. Creep stress exponent (n) values for all strain rates tested.

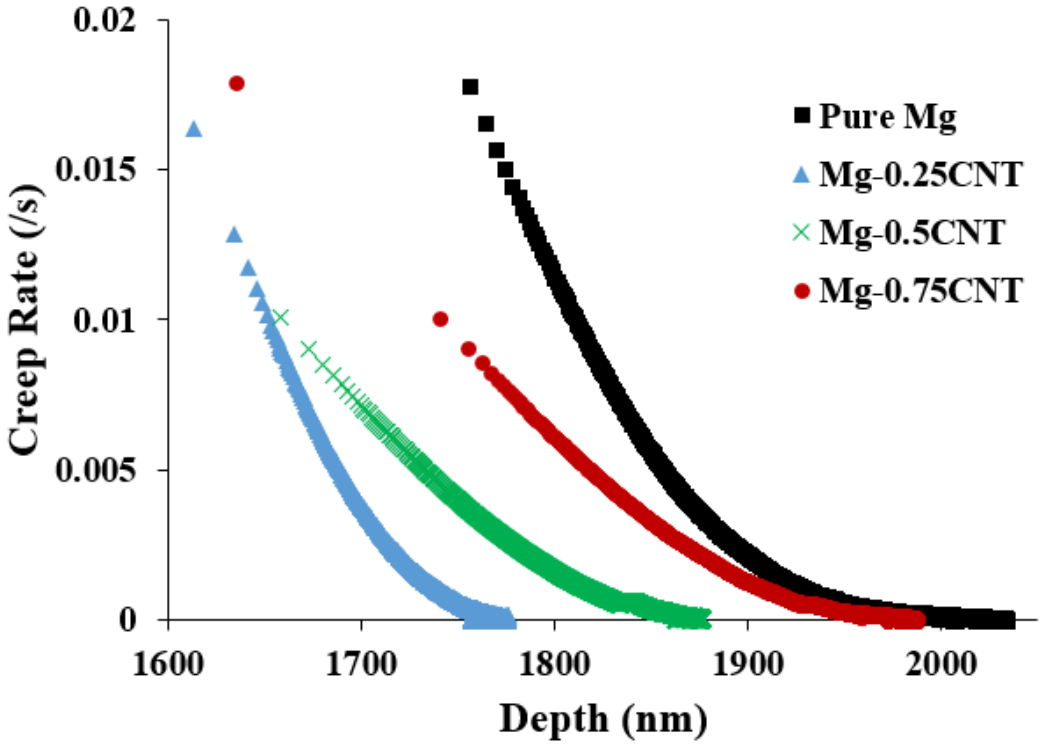


Figure 10. Creep rate versus indentation depth for pure magnesium and the Mg-CNT nanocomposites at the strain rate of 10 /s.