Polymer Replication on Nanoscale PRN 2021

Development of a novel high-performance self-lubricating micro/nano mould based on 2D material nanocomposite

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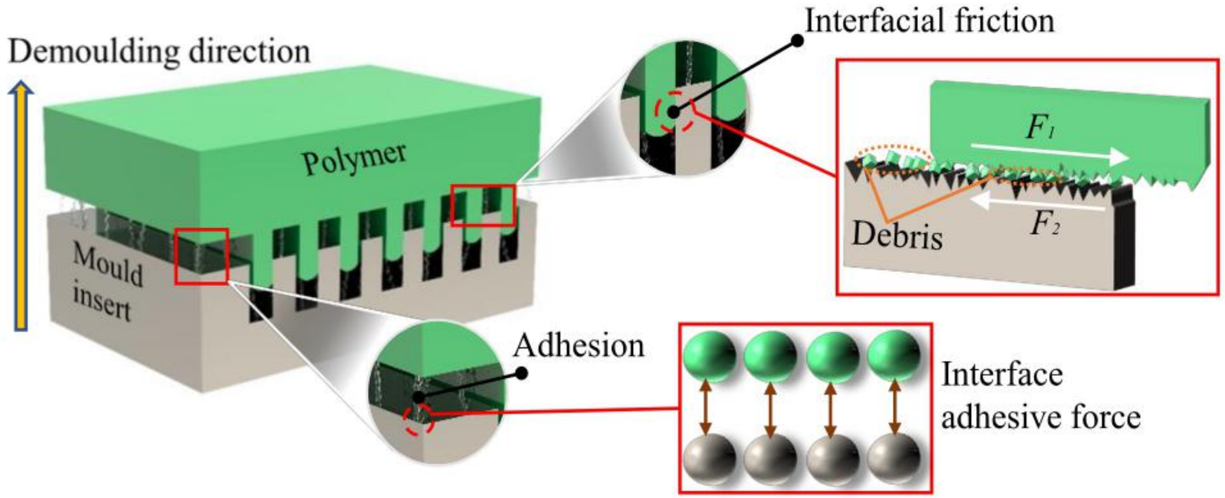
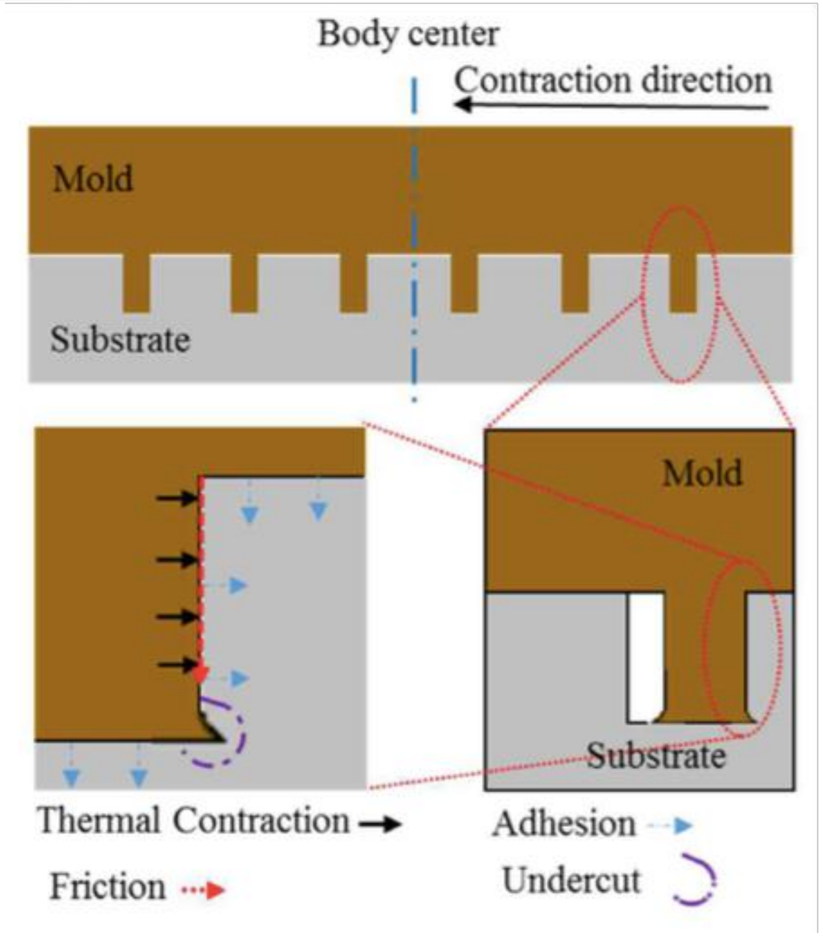
07/05/2021

BACKGROUND



[1]

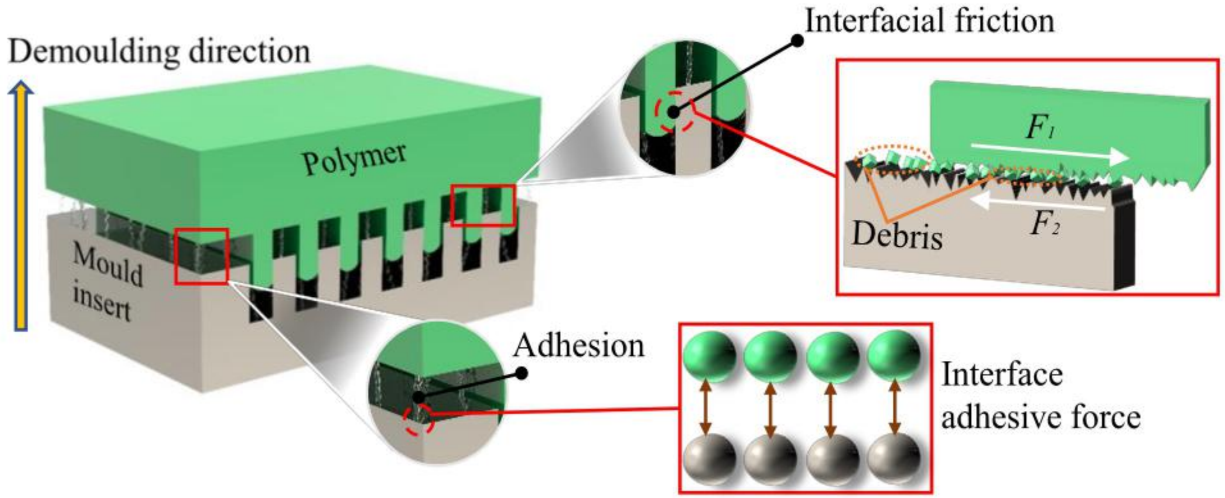


Mismatch of thermal expansion coefficient:

Nickel: $K=13\times10^{-6}$ $1/K$, PMMA: $K=70\times10^{-6}$ $1/K$

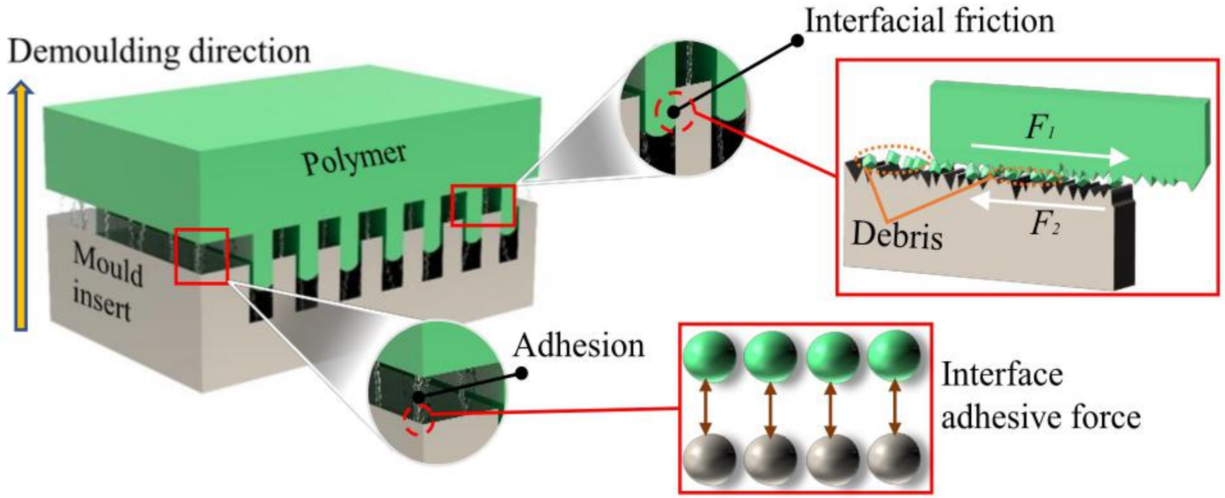
[1] Saha, B., Toh, W.Q., Liu, E., Tor, S.B., Hardt, D.E. and Lee, J., 2015. Journal of Micromechanics and Microengineering, 26(1), p.013002.

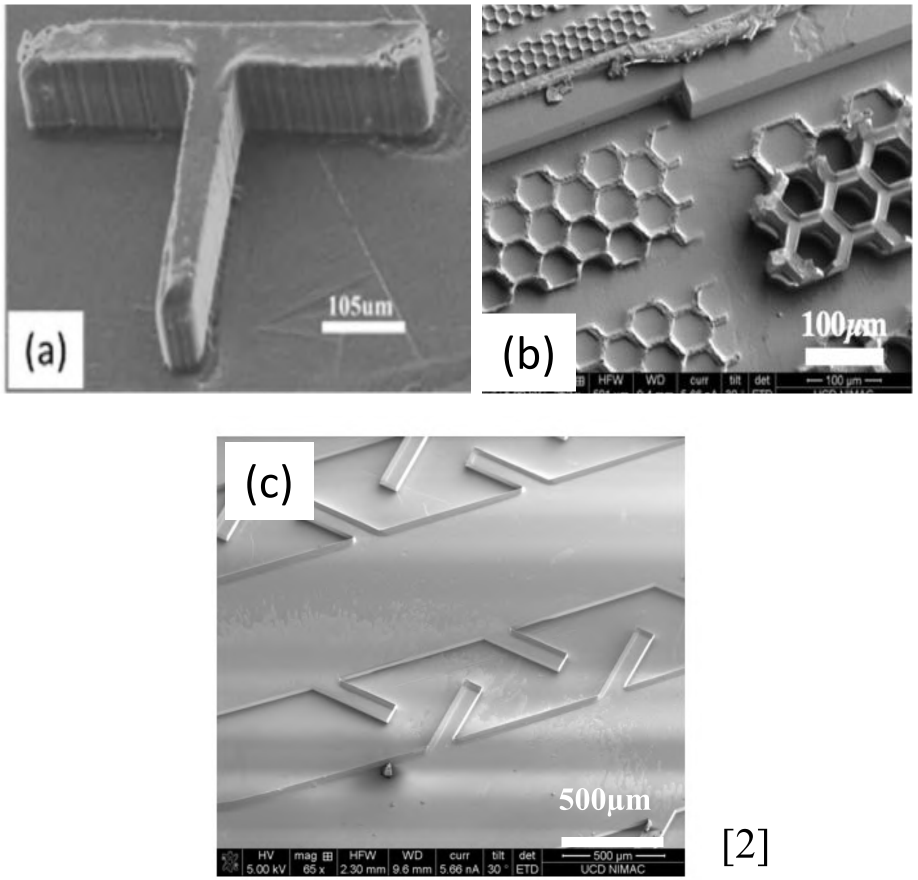
BACKGROUND



- Demolding force (adhesion and friction)
  - Chemical interaction
    - Covalent bond
    - Molecular interactions
  - Mechanical Interaction
    - Interlocking of surface roughness
    - Friction from sidewall
    - Undercut

BACKGROUND





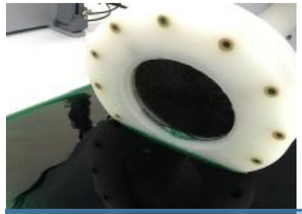
[2]

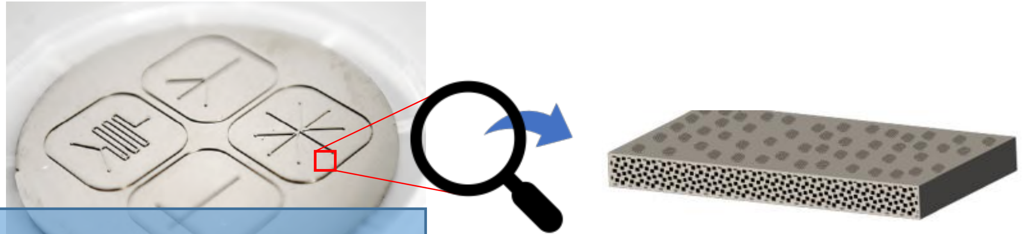
Distortion and damage of surface micro patterns

[2] Zhang, N., Zhang, H., Stallard, C., Fang, F. and Gilchrist, M.D., 2018. CIRP Journal of Manufacturing Science and Technology, 23, pp.20-38.

MOTIVATION

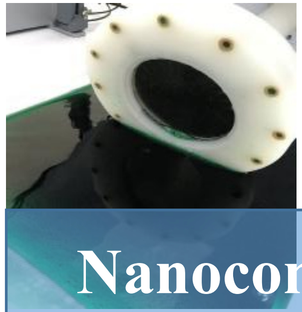
Coatings	Friction coefficient	Coating methods	Advantages	Disadvantages
Fluoropolymer coatings (PTFE, PFPE, FEP)	0.05~0.1	PVD, CVD,	Hydrophobic surface	• Poor wear resistance • Lower service temperature
Cubic boron nitride (c-BN) coating	• Dry: 0.2~0.6 • Humid: <0.1	CVD	• High service temperature • High oxidation resistance • High wear resistance	• Poor adhesion to the substrate • High residual stress • Expensive coating facility
Self-assembled monolayer coatings (SAM)	0.07~0.1	Dip coating Molecular vapor deposition	Low-cost process	• Low wear resistance • Low thermal stability
Diamond-like carbon (DLC)	• Dry: 0.001~0.05 • Humid: 0.2~0.3	Sputtering, thermal evaporation, PECVD	• High hardness • Low friction	• High internal stress • Poor adhesion to substrate • Restriction in thickness • Expensive to CVD coating
Graphene/ Graphene oxide	• Dry: 0.15~0.2 • Humid: 0.15~0.2	CVD, Chemical and mechanical exfoliation	• Stable coefficient of friction; • Good filler material	• Difficult for large-area coatings • 0.1-0.2 nm coating thickness
MoS_2 and WS_2	• Dry: 0.02~0.06 • Humid: 0.15~0.25	Sputtering, thermal evaporation, CVD	High temperature	• Lower wear resistance of MoS_2 • WS_2 loses its lubricating properties in humid environments

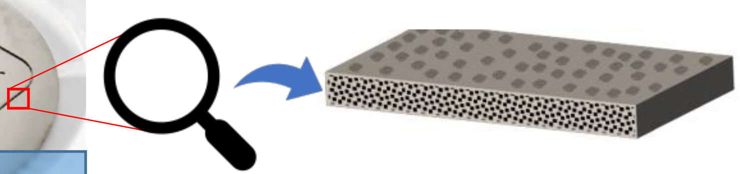




Nanocomposite electroforming

MOTIVATION



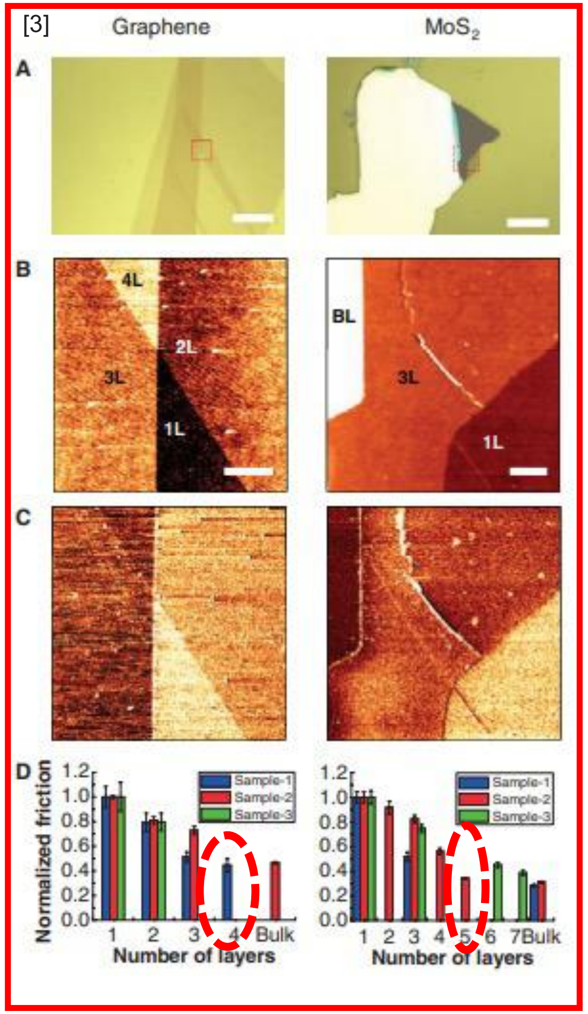


Nanocomposite electroforming

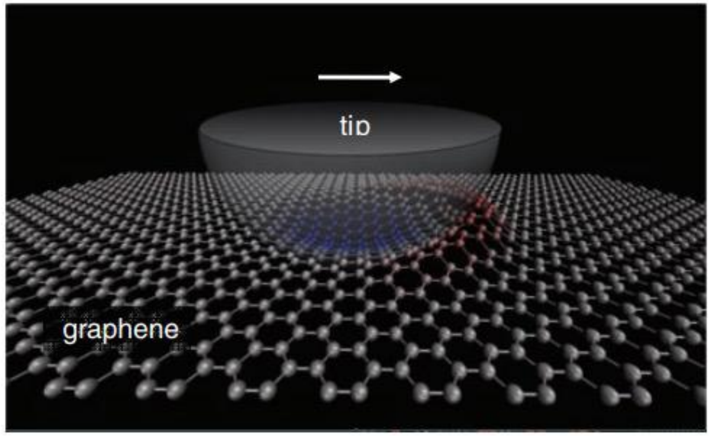
High performance mould (patent-pending)

- ✓ Mechanical properties: *High microhardness and longer tool life*
- ✓ Tribological properties: *Low friction and adhesion*
- ✓ Surface roughness: *Less than 100nm*
- ✓ Dimensional accuracy: *high dimensional accuracy*

2D MATERIALS SELECTION



AFM tip-based technology



Few layers are best !!

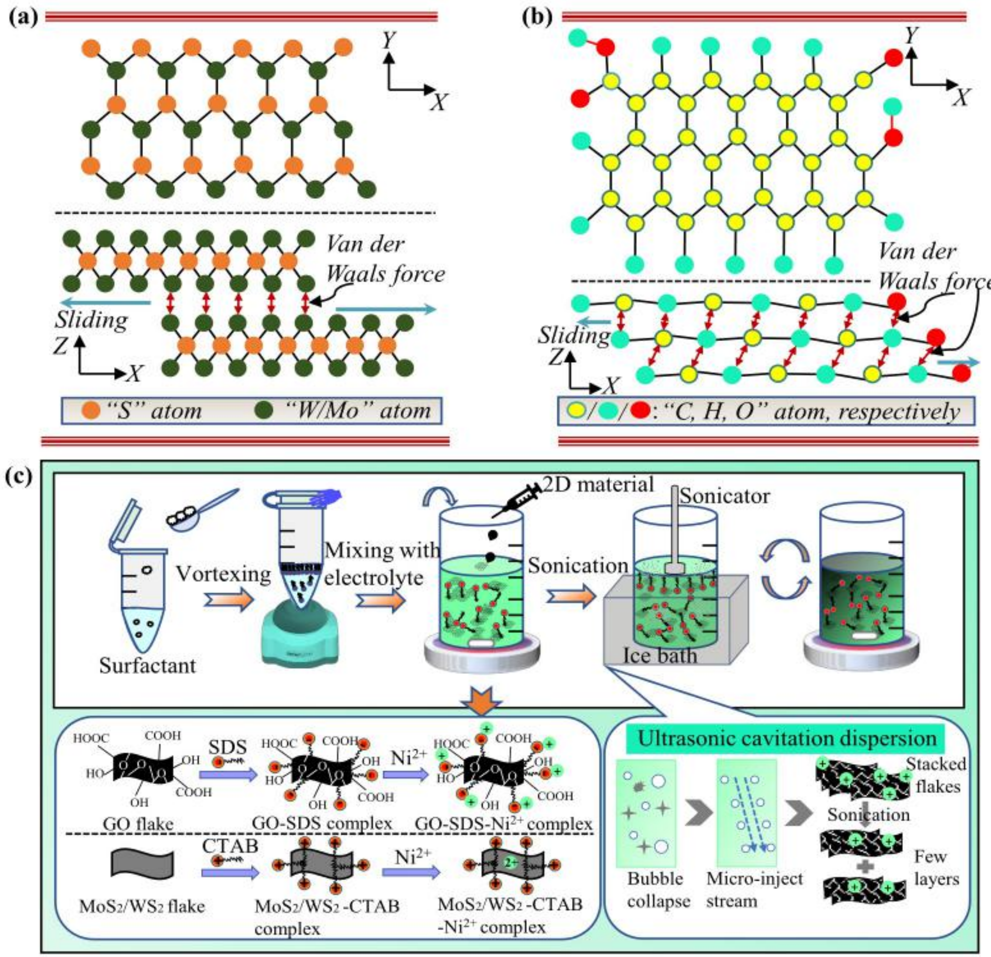
Experimental methods:

✓ Types of 2D material:
GO; MoS_2 ; WS_2

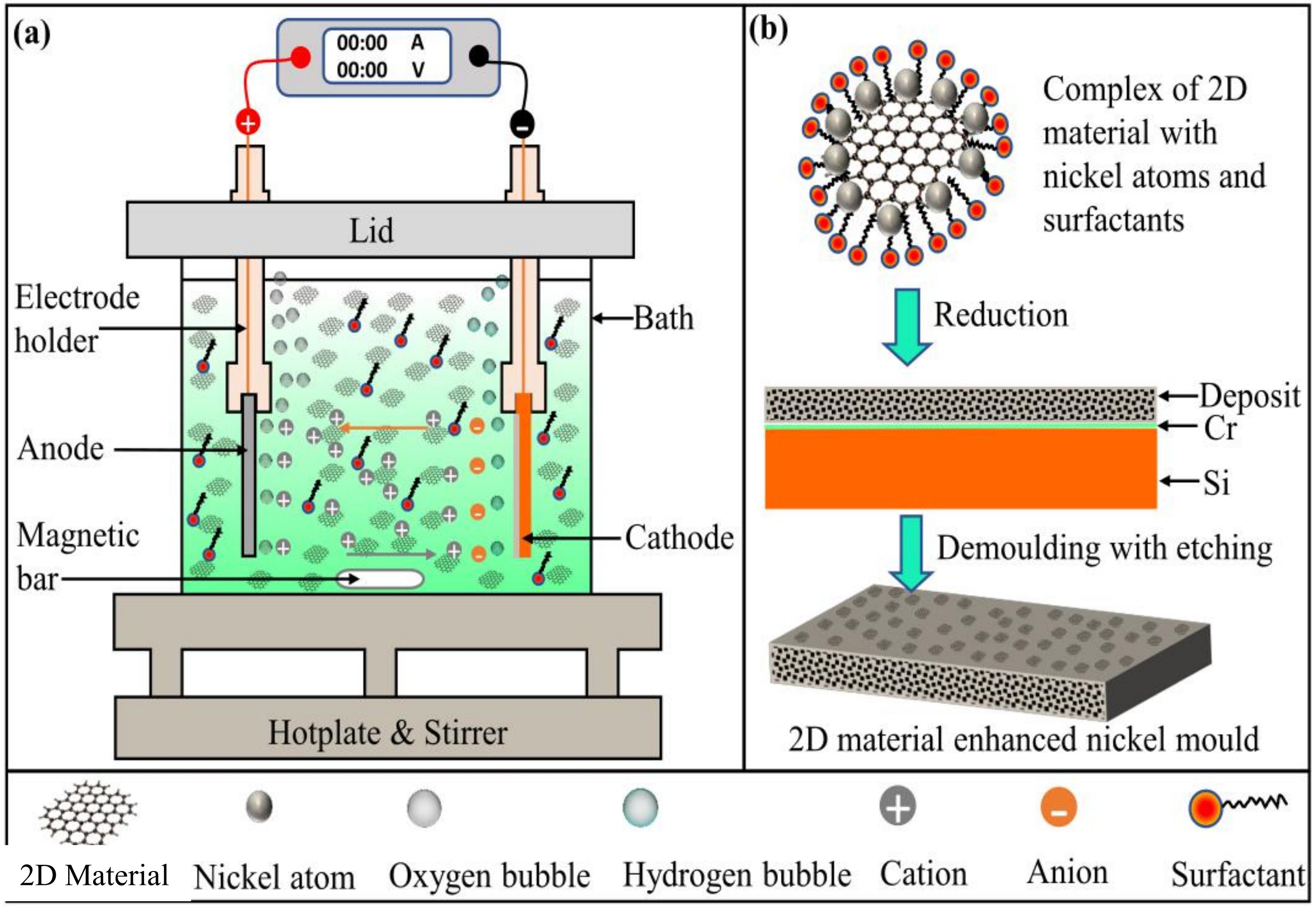
✓ Concentration of 2D material:
GO & MoS_2 : 0.1, 0.2, 0.5, 1.0 g/L
WS_2 : 0.1, 0.14, 0.2, 0.5 g/L

[3] Lee, Changgu, et al. "Frictional characteristics of atomically thin sheets." *science* 328.5974 (2010): 76-80.

ELECTROLYTE PREPARATION



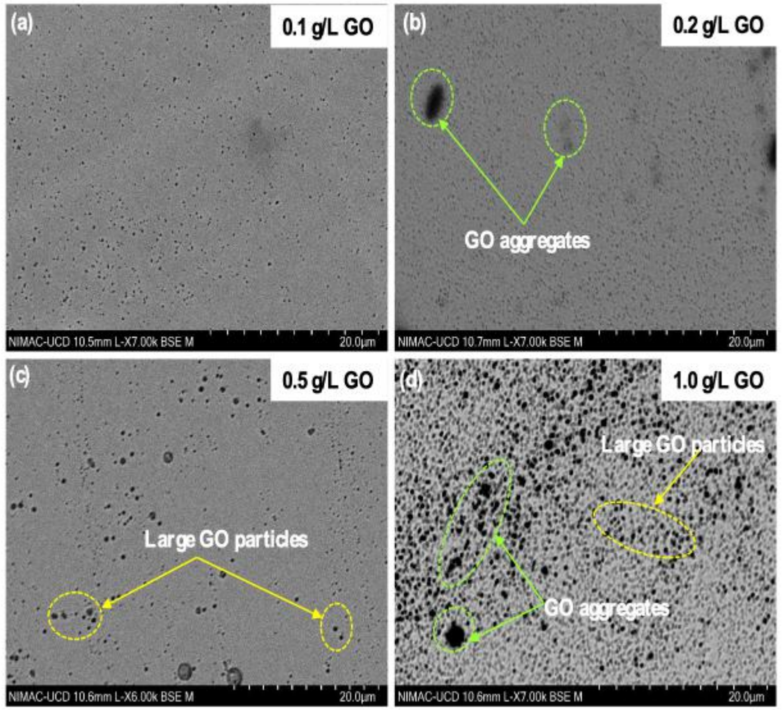
Structures of few-layered MoS_2/WS_2 (a) and GO (b), respectively; preparation of electroforming solution containing 2D materials dispersion (c).



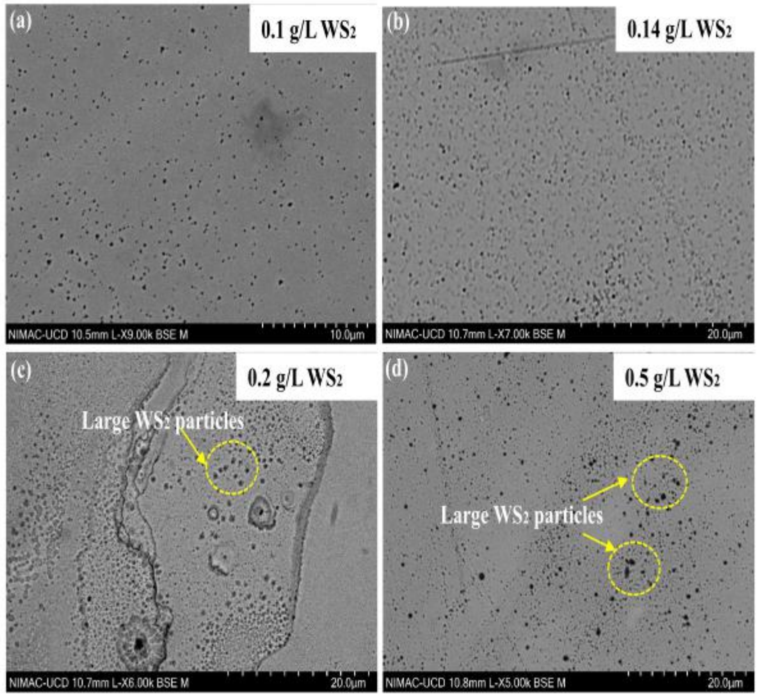
Electroforming experimental setup for the fabrication of 2D materials reinforced nickel moulds (a) and related demoulding method for releasing electroformed moulds (b).

SURFACE MORPHOLOGY

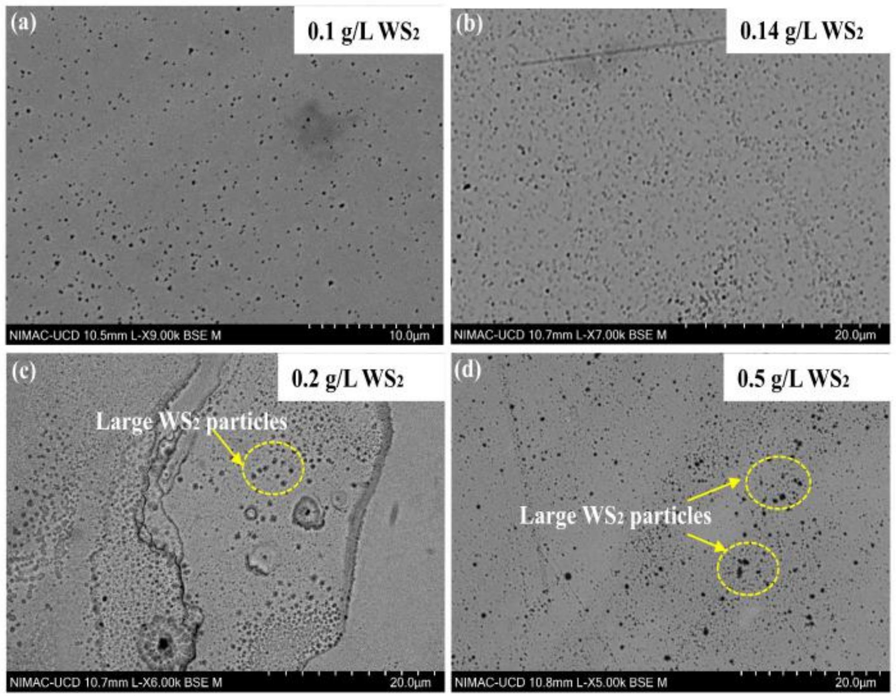
Nickel/GO composite moulds



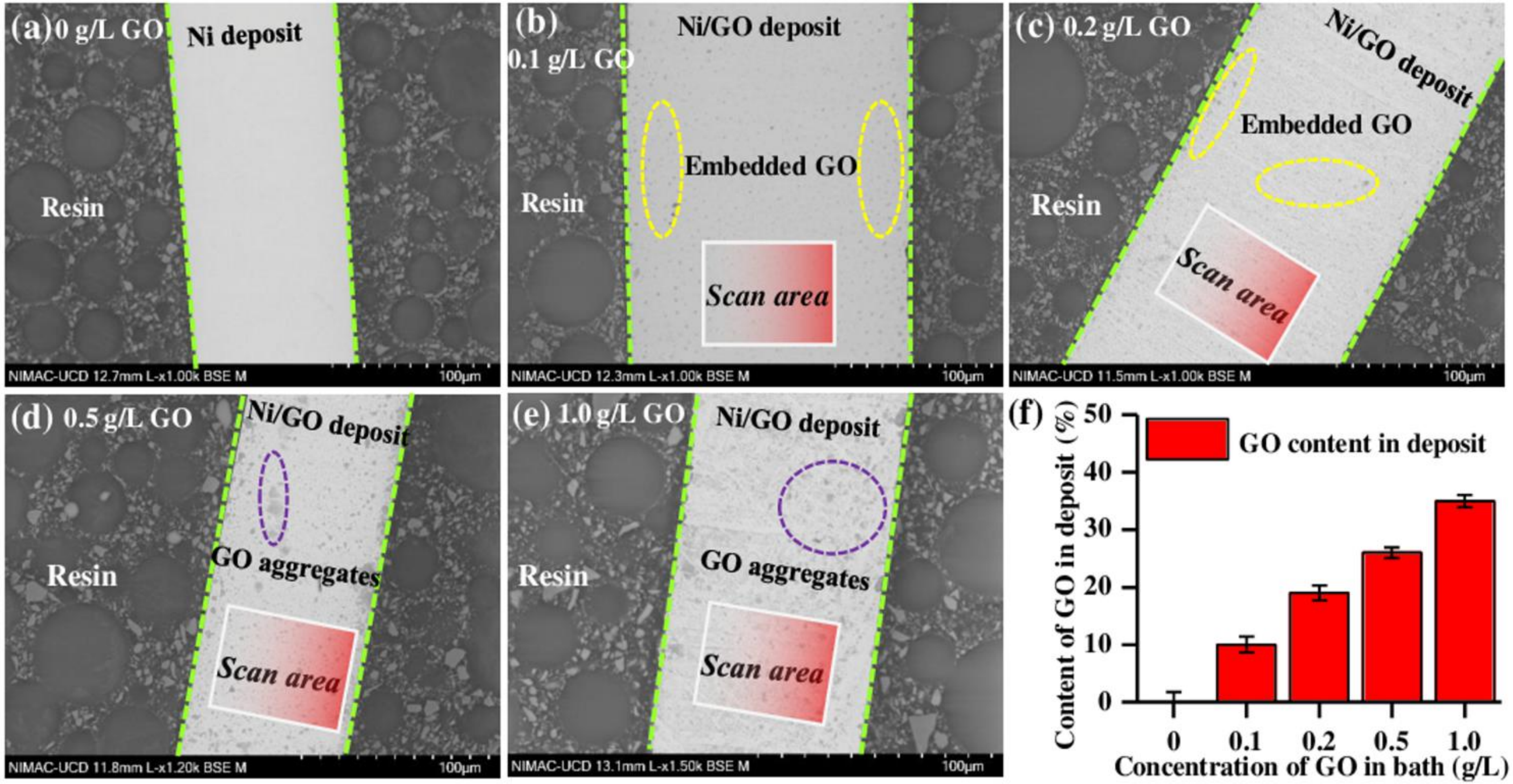
Nickel/MoS_2 composite moulds



Nickel/WS_2 composite moulds

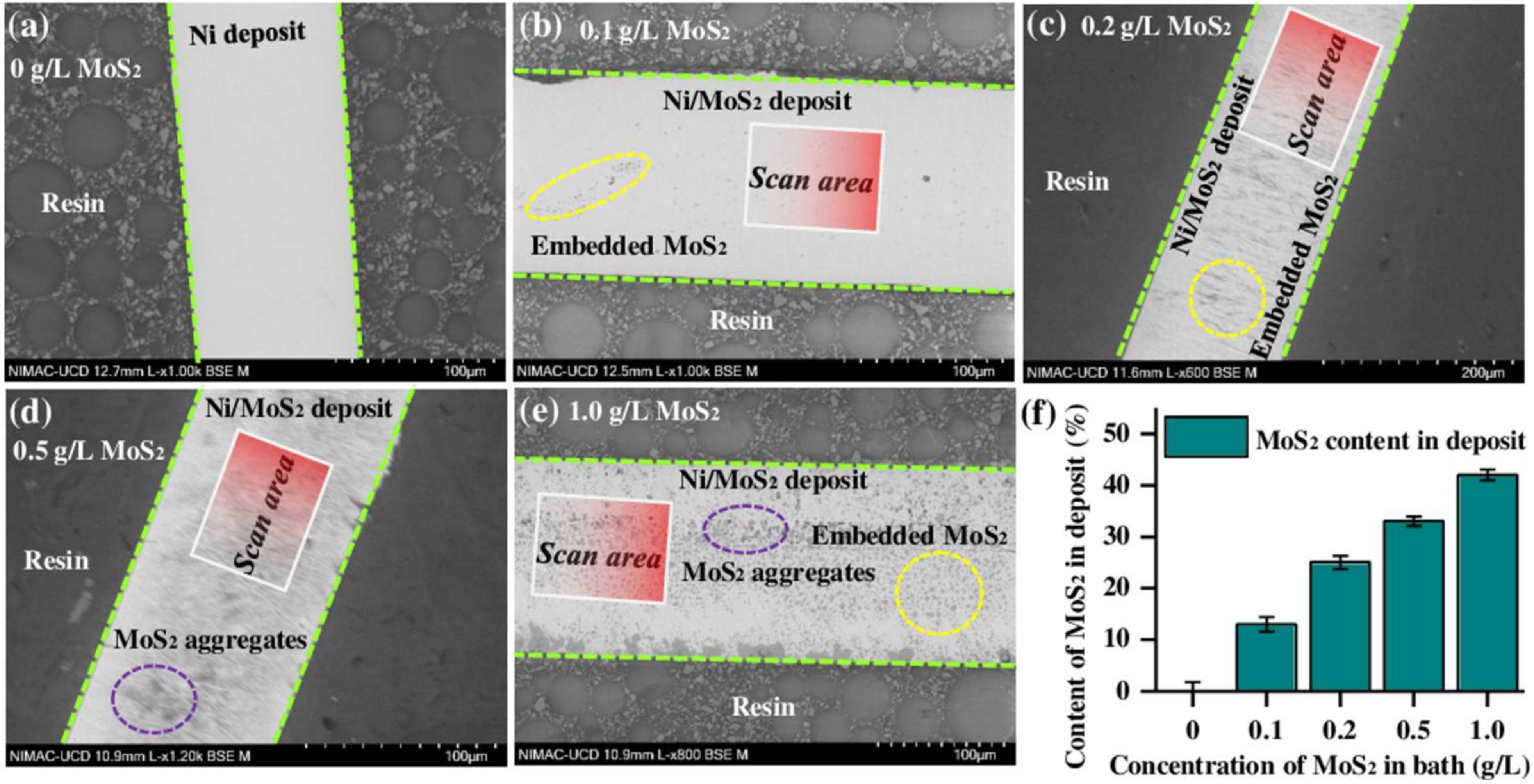


CROSS-SECTION MORPHOLOGY OF NICKEL/ GO MOULDS



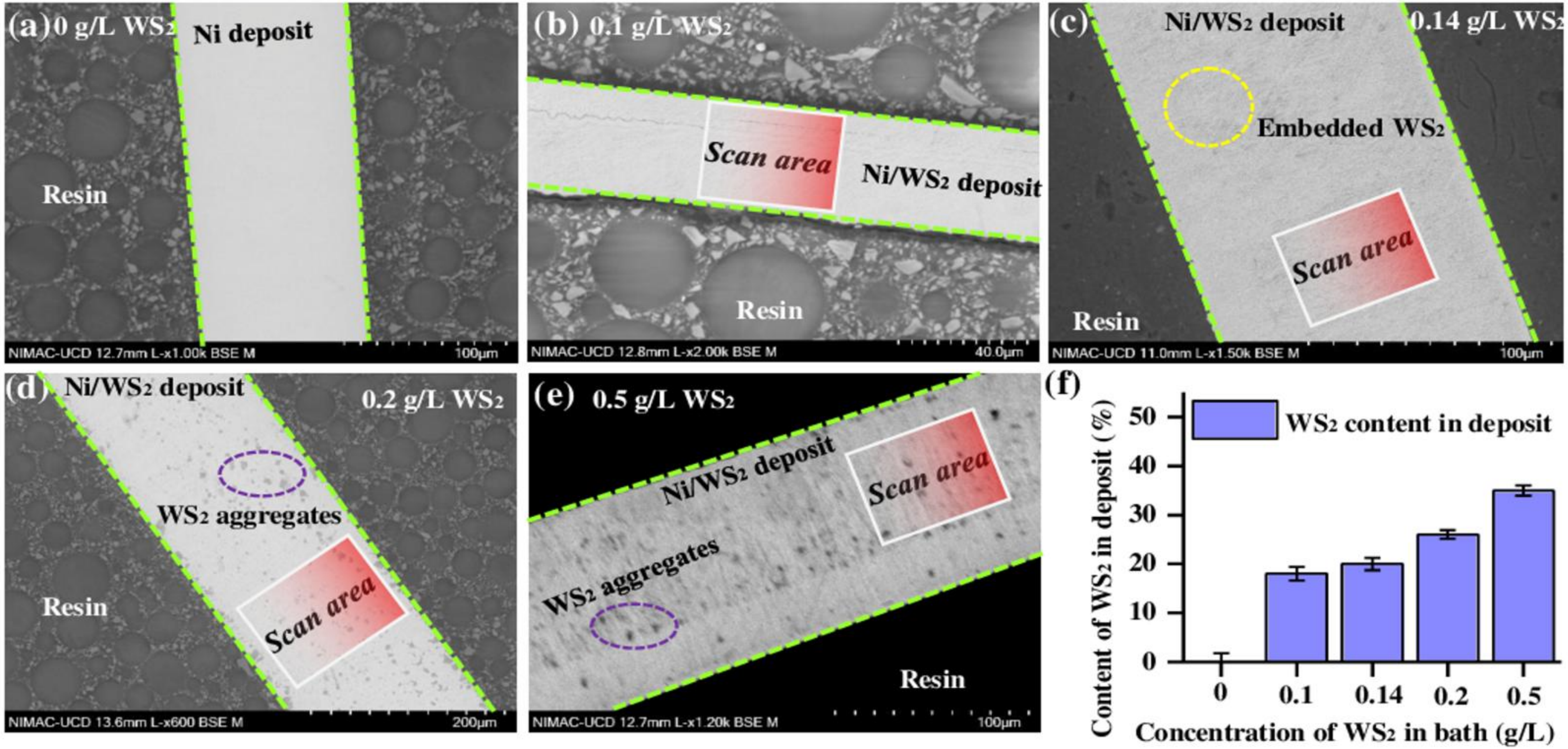
Cross-section morphology of electroformed nickel/GO composite moulds, fabricated in nickel sulfamate bath with various concentrations of GO: (a) 0.1 g/L GO; (b) 0.2 g/L GO; (c) 0.5 g/L GO; (d) 1.0 g/L GO; and corresponding GO content in the deposit (f), where the content of GO is determined by C content in the deposit.

CROSS-SECTION MORPHOLOGY OF NICKEL/M_OS_2 MOULDS



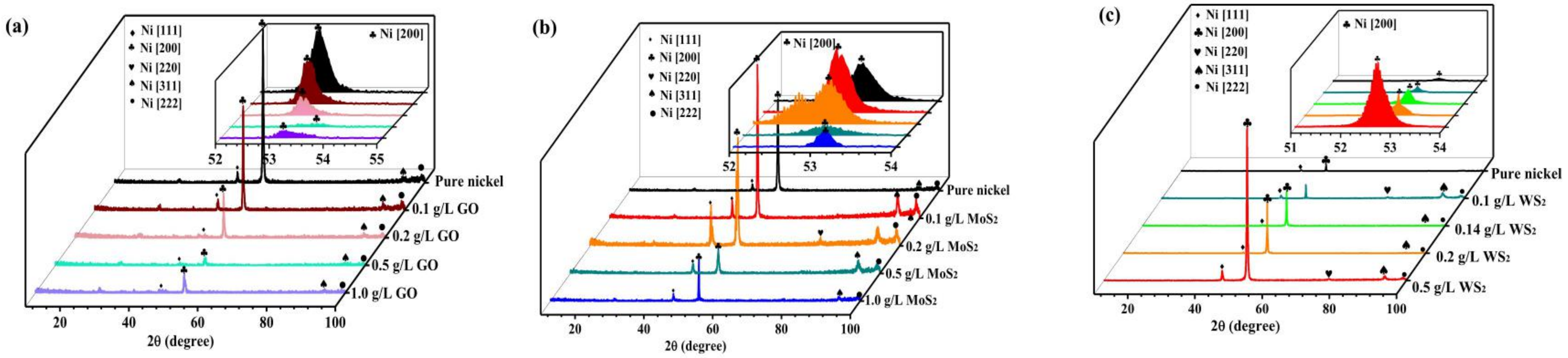
Cross-section morphology of electroformed nickel/MoS_2 composite moulds (a-e), fabricated in nickel sulfamate bath with various concentrations of MoS_2: (a) 0.1 g/L MoS_2; (b) 0.2 g/L MoS_2; (c) 0.5 g/L MoS_2; (d) 1.0 g/L MoS_2; and corresponding MoS_2 content in the deposit (f), where the content of MoS_2 is determined by Mo content in the deposit.

CROSS-SECTION MORPHOLOGY OF NICKEL/WS_2 MOULDS



Cross-section morphology of electroformed nickel/WS_2 composite moulds (a-e), fabricated in nickel sulfamate bath with various concentrations of WS_2 : (a) 0.1 g/L WS_2; (b) 0.14 g/L WS_2; (c) 0.2 g/L WS_2; (d) 0.5 g/L WS_2; and corresponding WS_2 content in the deposit (f), where the content of WS_2 is determined by W content in the deposit.

MICROSTRUCTURE ANALYSIS



XRD patterns of electroformed pure nickel mould and nickel composite moulds fabricated in nickel sulfamate bath with various concentrations of 2D materials: (a) nickel/GO composite moulds; (b) nickel/MoS_2 composite moulds; (c) nickel/WS_2 composite moulds.

Sherrer's equation

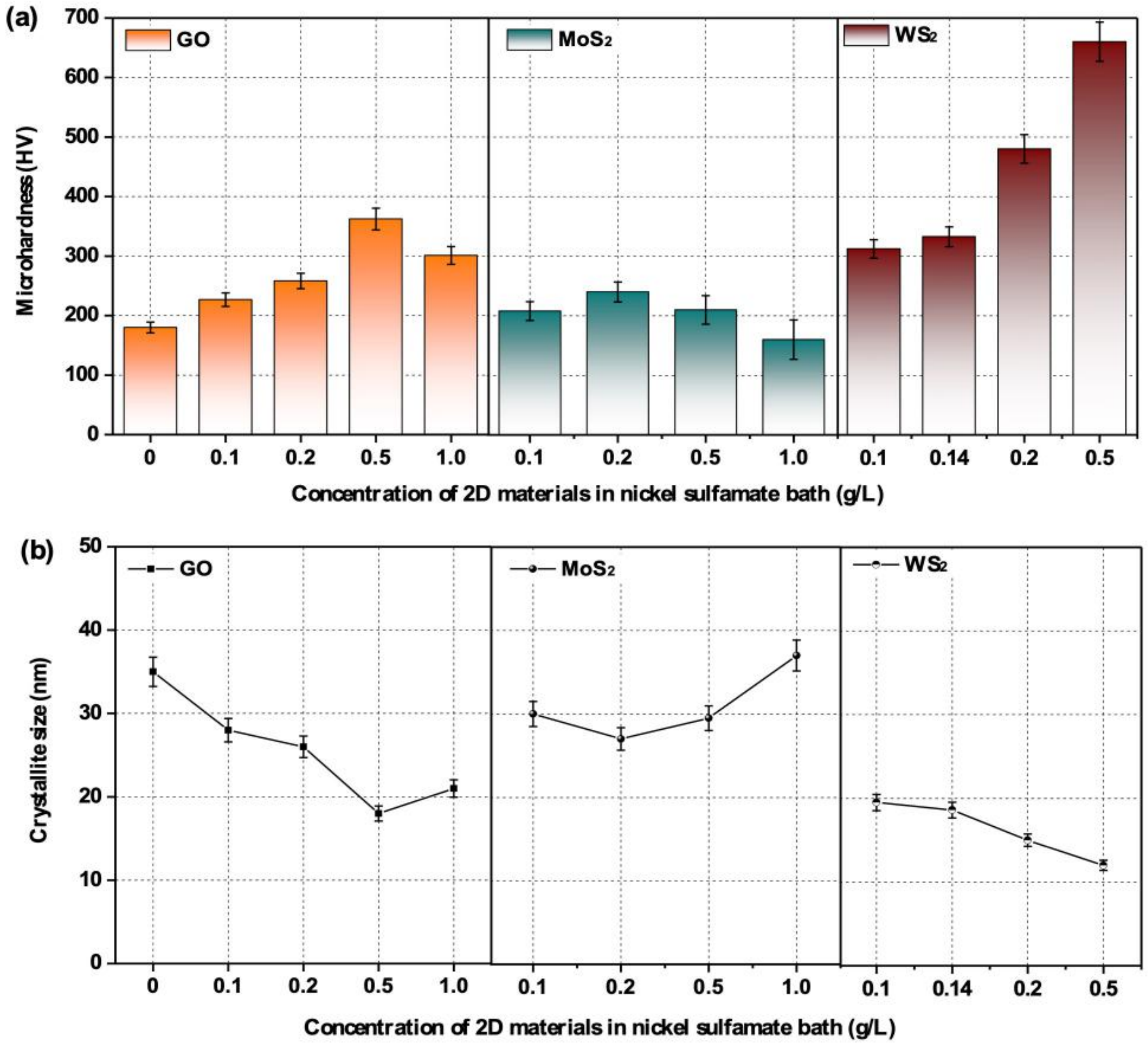
$$L = \left(\frac{K\lambda}{\beta \ \cos\theta}\right)$$

- *L* is the average crystallite size, *β* *is* the *full-width half (FWHM)* maxima.
- *FWHM* is used to calculate the crystallite size.

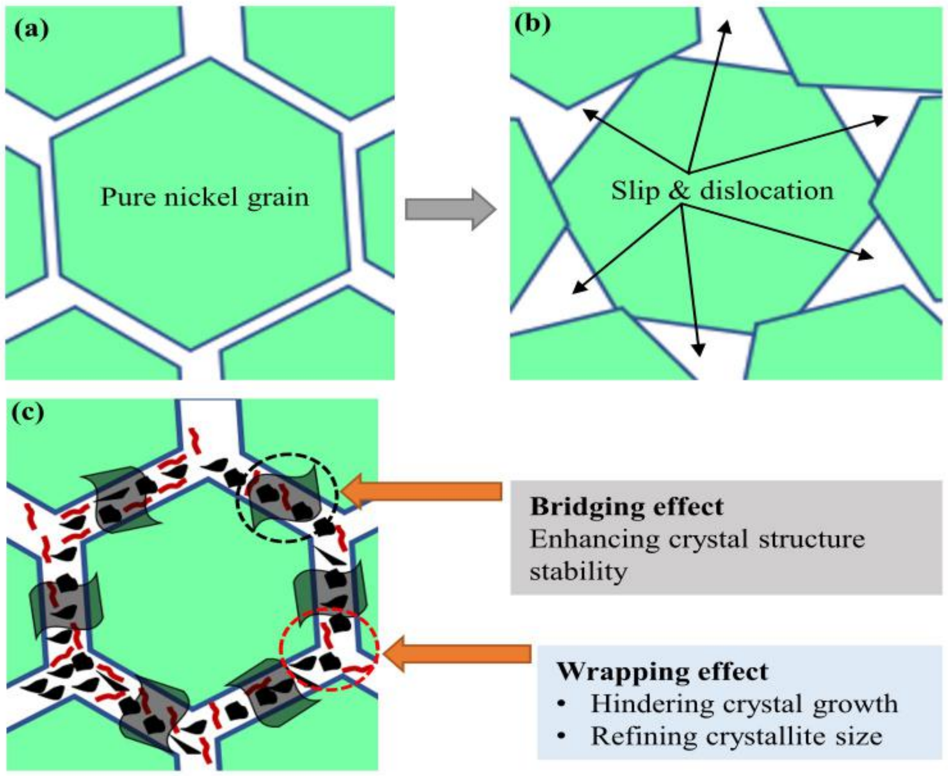
❑ *FWHM broadening* means the *refinement* of crystallite size.

❑ FWHM is broadening with *increasing 2D materials concentration* and the cases of *WS_2* are more *prominent*.

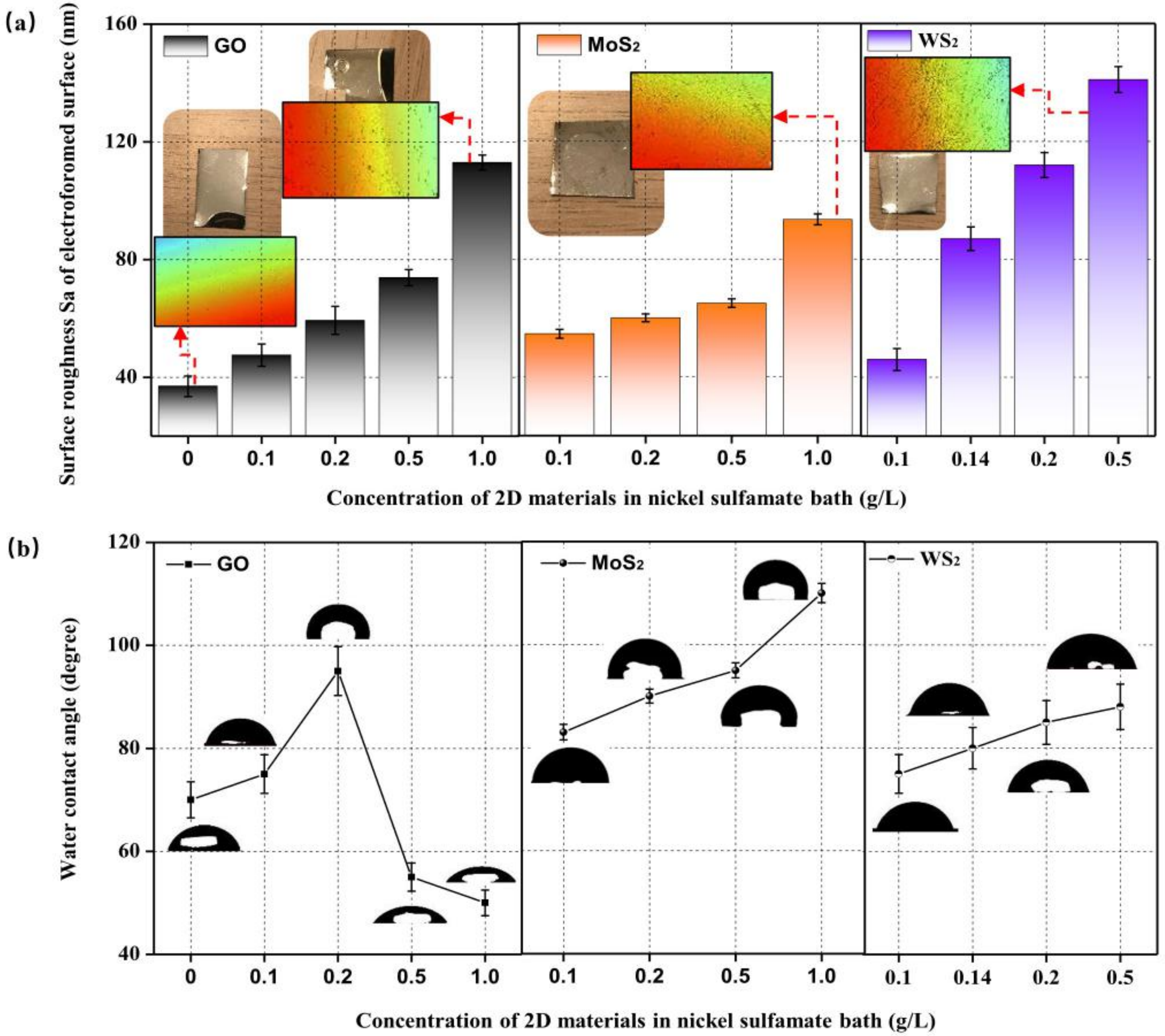
MICROHARDNESS AND CRYSTALLITE SIZE



Hardness enhancement mechanism



SURFACE ROUGHNESS AND WETTABILITY ANALYSIS



Surface roughness increases because of embedding of 2D materials

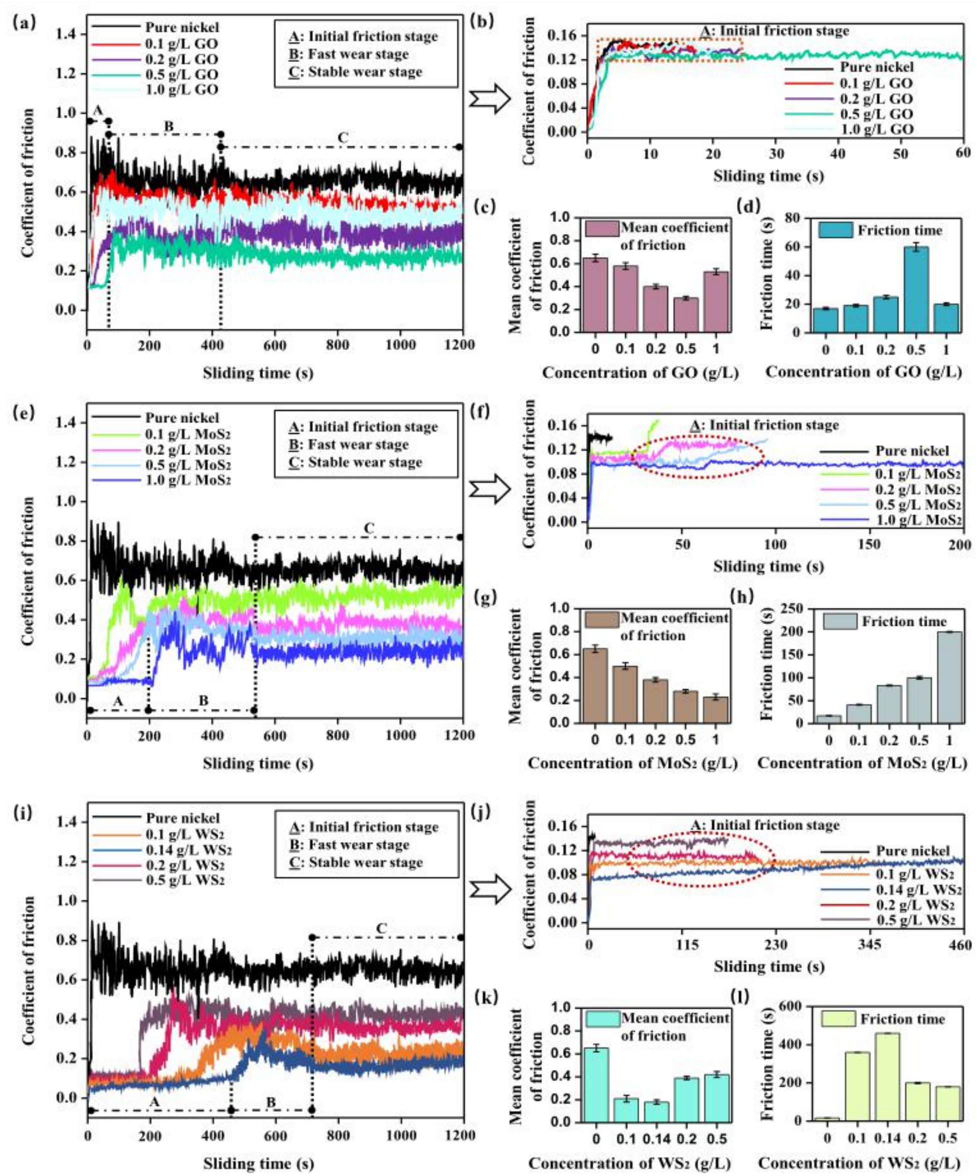
Wettability varies with 2D materials concentration and surface topography from hydrophilic to hydrophobic

FRICTION COEFFICIENT

Nickel/GO mould

Nickel/MoS_2 mould

Nickel/WS_2 mould



Friction stage: wear morphology

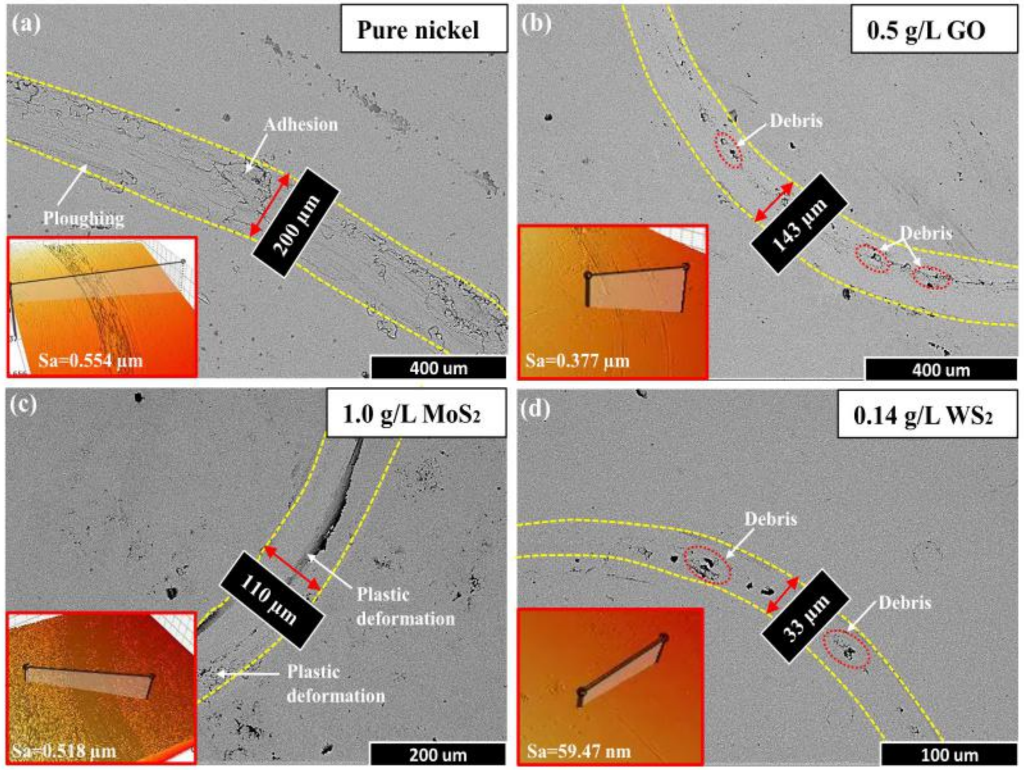
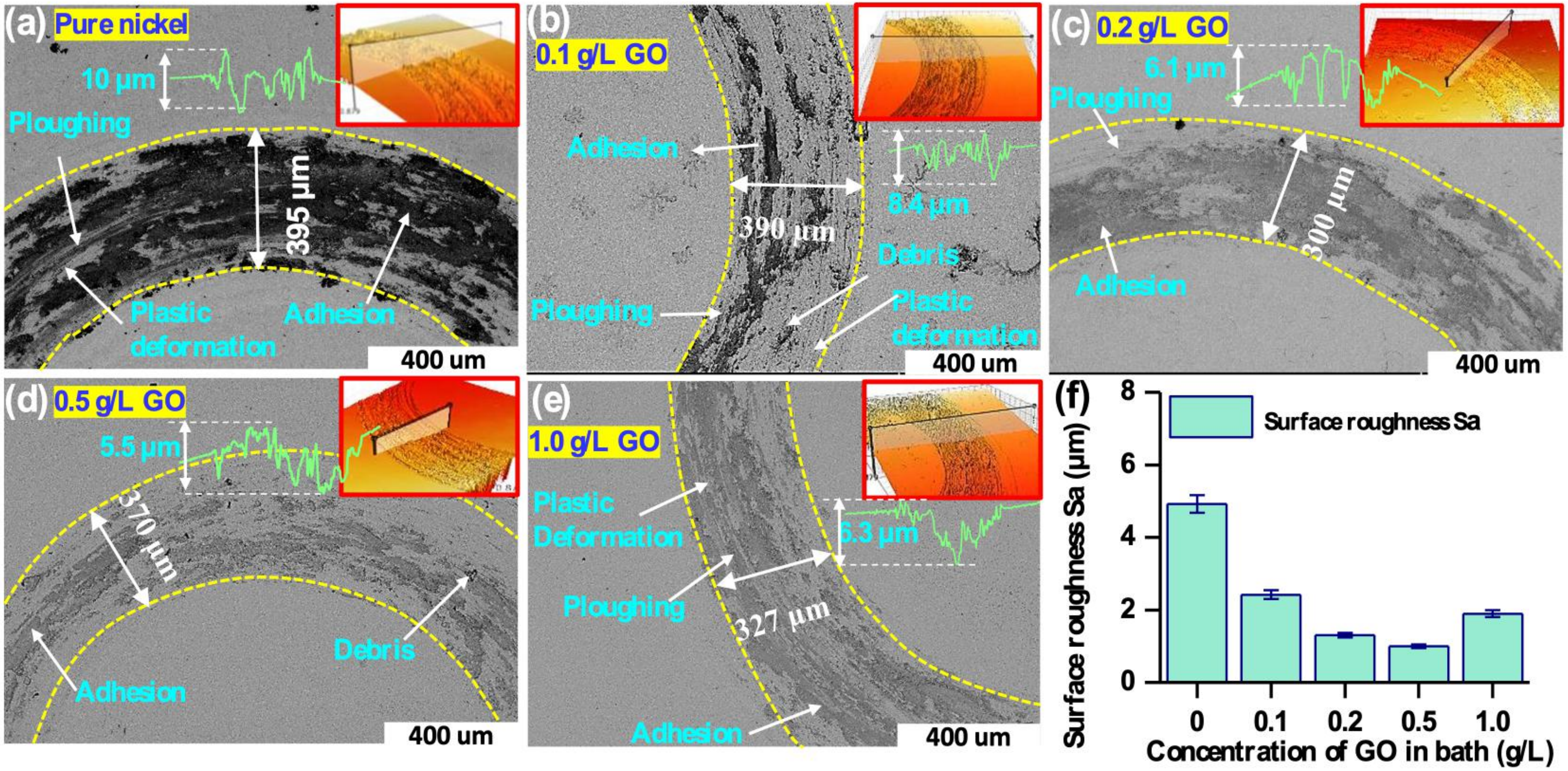
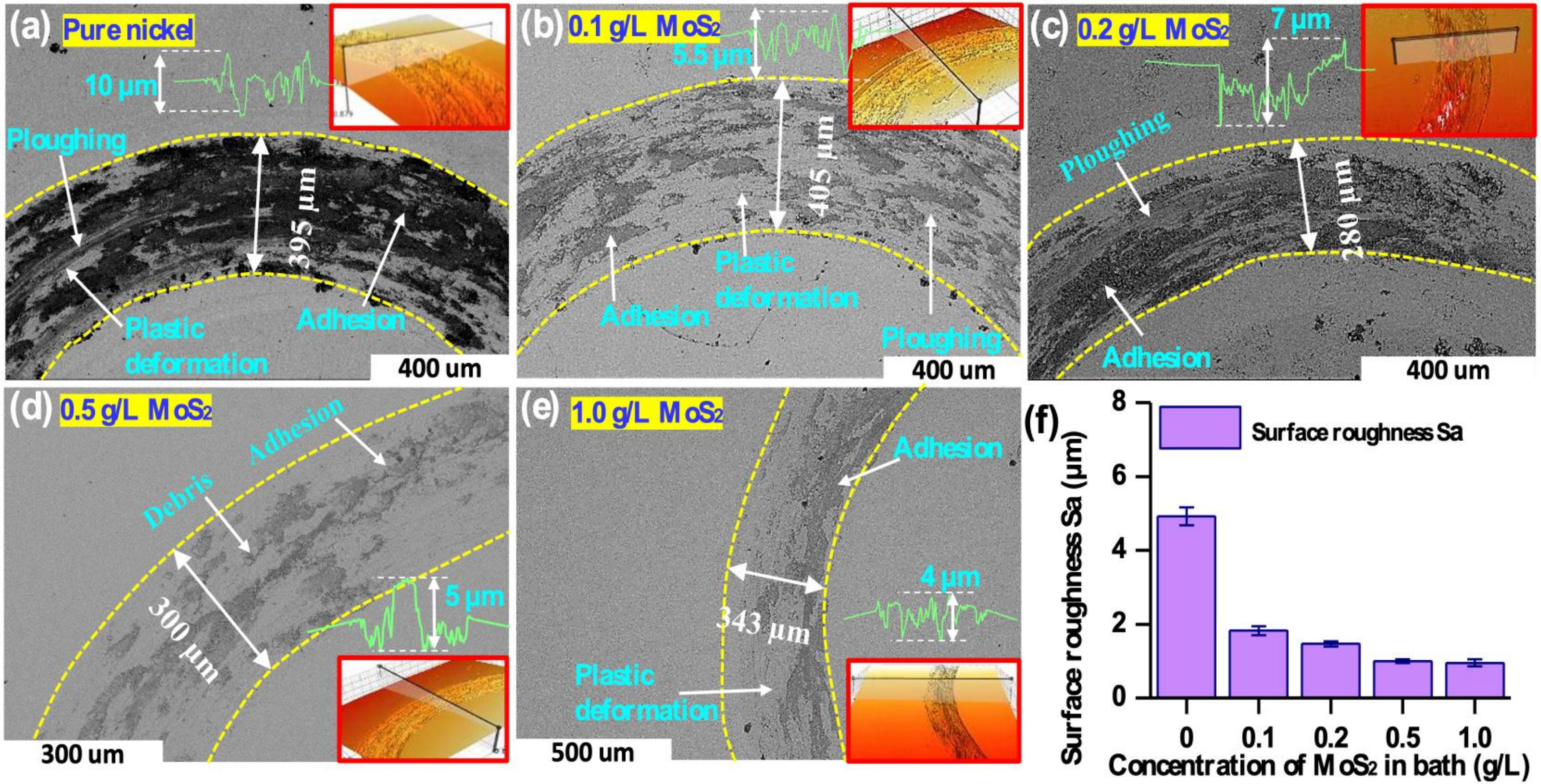


Figure 16. Wear morphology of pure nickel and nickel/2D material composite moulds during the initial friction stage: (a) pure nickel; (b) 0.5 g/L GO; (c) 1.0 g/L MoS_2; (d) 0.14 g/L WS_2. Note that selected concentrations of 2D materials are optimal to their respective lowest coefficient of friction.

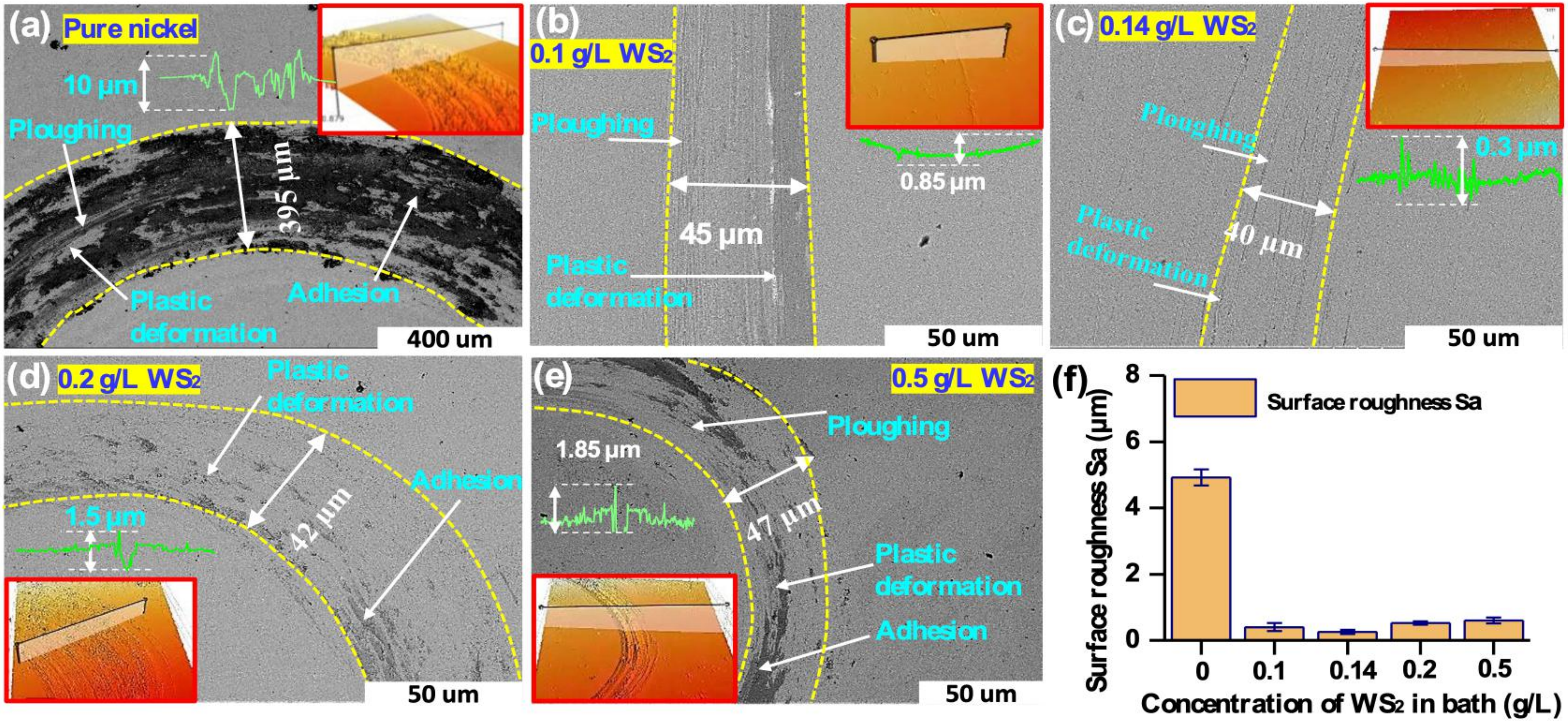
WEAR MORPHOLOGY OF NICKEL/ GO MOULDS



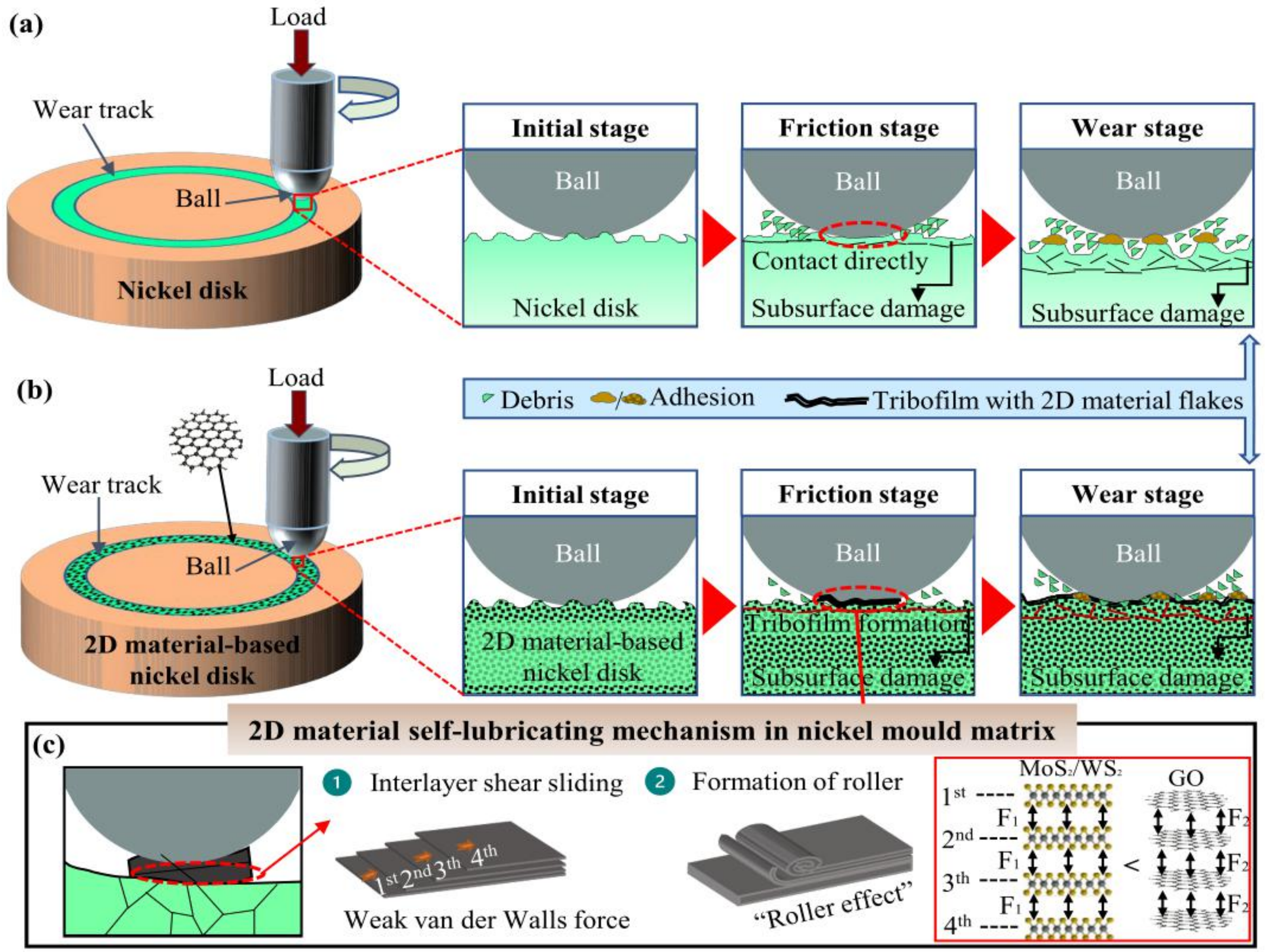
WEAR MORPHOLOGY OF NICKEL/M_OS_2 MOULDS



WEAR MORPHOLOGY OF NICKEL/WS_2 MOULDS



SELF-LUBRICATING MECHANISM OF NICKEL/2D MATERIALS MOULD



Schematic illustration of wear mechanisms of pure nickel mould (a); self-lubricating mechanisms of 2D materials enhanced nickel moulds (b) and (c).

CONCLUSION

- *A low concentration of 2D materials* is recommended to be used to achieve homogenous distribution in the electroformed moulds.
- The role of GO and MoS_2 in enhancing the performance of nickel mould tools is reflected in mechanical properties and tribological properties, respectively, whereas WS_2 is both compatible and more significant.
- The incorporation of 2D materials not only modulates the nickel matrix grains growth but also easily forms *self-lubricating transfer film,* especially for *WS_2/MoS_2*.
- The main wear mechanism is altered from *abrasive-dominated wear* for pure nickel mould to *adhesion-dominated wear* for nickel/2D materials composite moulds.
- Maximum microhardness of ~660 HV is achieved from 0.5 g/L WS_2, indicating a *3.67 times* increase compared with pure nickel mould.
- A low concentration *(0.14 g/L) of WS_2* shows the lowest COF, where the COF in the initial friction stage is *0.08*, implying a decrease of 42.8% and *27 times increase in a lifetime*, compared with pure nickel mould.

manufacturing

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Thank you for your kind attention!

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