# Compositional gradient nanocrystalline Ni-W coatings by electrodeposition for superior wear resistance


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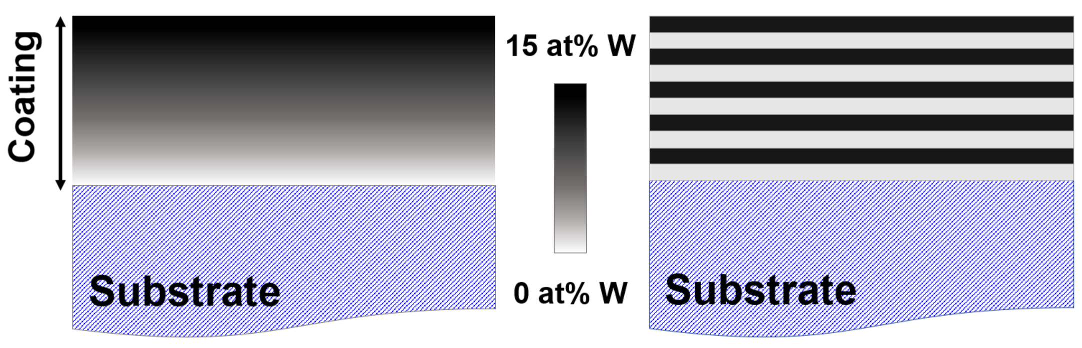
## Abstract


The hard nanocrystalline coatings are often deposited to improve the wear resistance. However, due to their poor toughness and strain hardening ability, nanocrystalline coatings suffer from the formation of delaminating tribo-layers and therefore high friction coefficients[1]. In recent studies, compositional and/or microstructural gradient nanocrystalline metals have demonstrated improved toughness while retaining their inherent high strength/hardness[2]. Therefore, the present study is aimed at extending the concept of compositional gradients to produce wear-resistant hard coatings.


## Introduction

- The presence of residual stresses in electrodeposited nanocrystalline coatings has been a longstanding problem especially in alloys like Ni-W.
- Effects of residual stresses[3]:
  - ✓ leads to delamination of coatings during deposition.
  - ✓ Cracking under the service conditions.
  - ✓ Formation of delaminating tribo-layers during wear.
  - ✓ Reduction in fatigue strength of substrate.
  - ✓ Warping of underlying fine features in MEMS.
- Literature: microstructural gradients can improve the strength-ductility synergy[2] and also wear properties[1].
- Therefore, in the present work, two types of gradient Ni-W coatings are investigated: 1. Continuous gradient and 2. Multilayers as shown in schematics below.

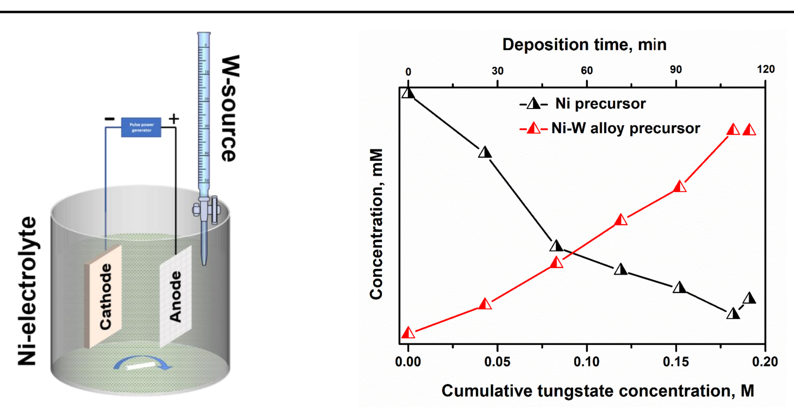



## Materials and Methods

- The standard ammonia-citrate bath[4] is chosen for the current study.
- Substrate: Mild steel, Anode: Platinum mesh
- Deposition by pulse electrodeposition technique.
- Coatings with minimum 30 µm thickness are deposited.
- ASTM G99 standard is followed for wear testing.

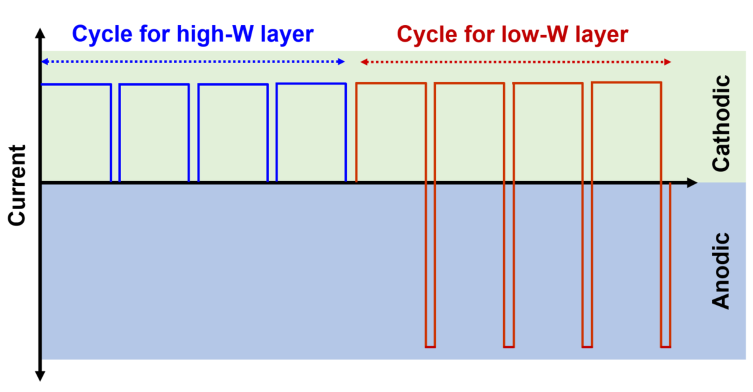
### ➢ Continuous gradient Ni-W

- The Ni-W bath is divided into two baths: 1. Source of Ni-ions, 2. Source of W-ions.
- Addition of W-source at regular intervals during deposition resulted in compositional gradient along the growth direction.



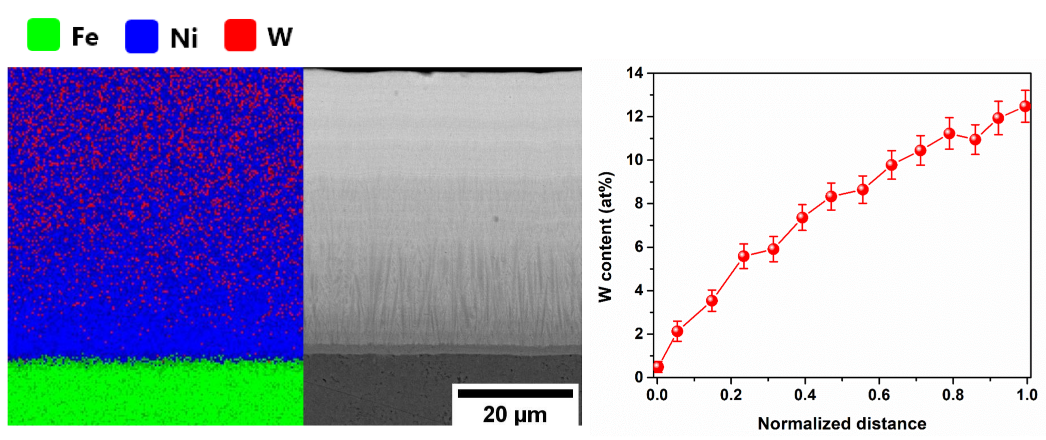

### ➢ Ni-W multilayers

- Deposition of multilayers consisting of alternative low-W and high-W layers by tuning the reverse current (anodic pulses).
- The layer thickness (λ) is tailored by adjusting the cycle duration. Range of λ investigated: 2500 nm to 50 nm.

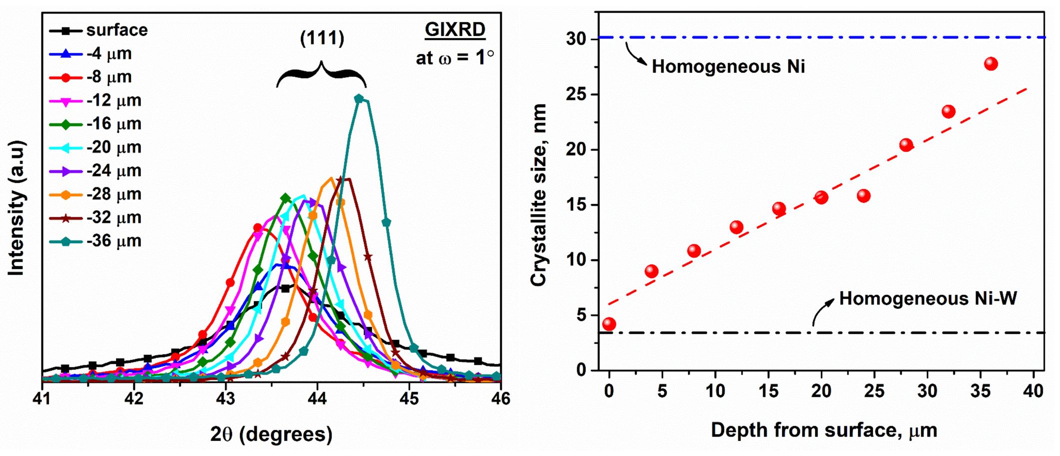


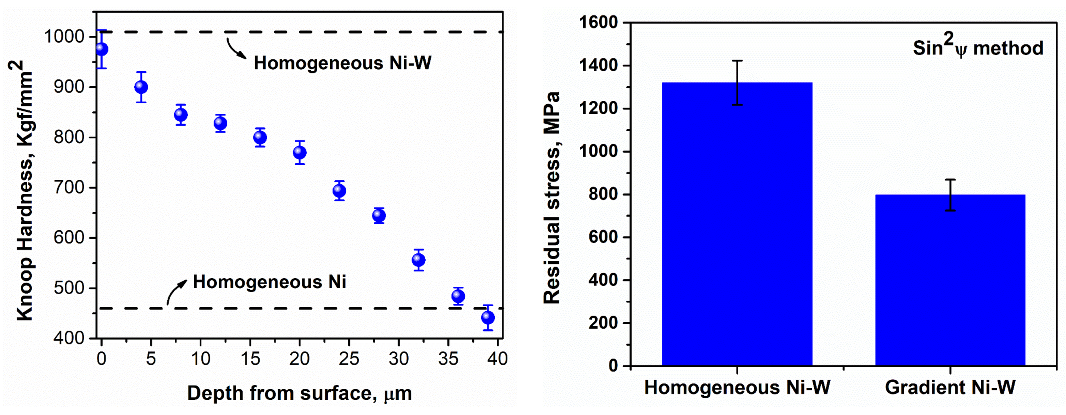

## Results: Characterization

### ➢ Continuous gradient Ni-W



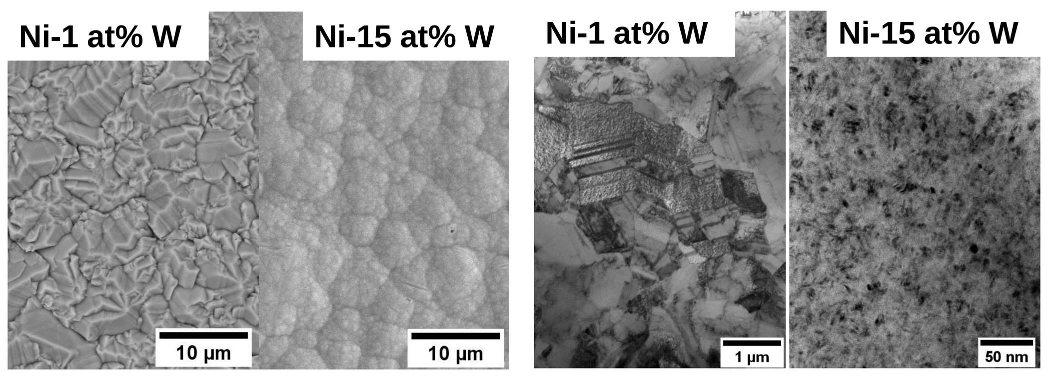

- Elemental mapping and EDS point analysis showing the gradient in W-content along the growth direction.



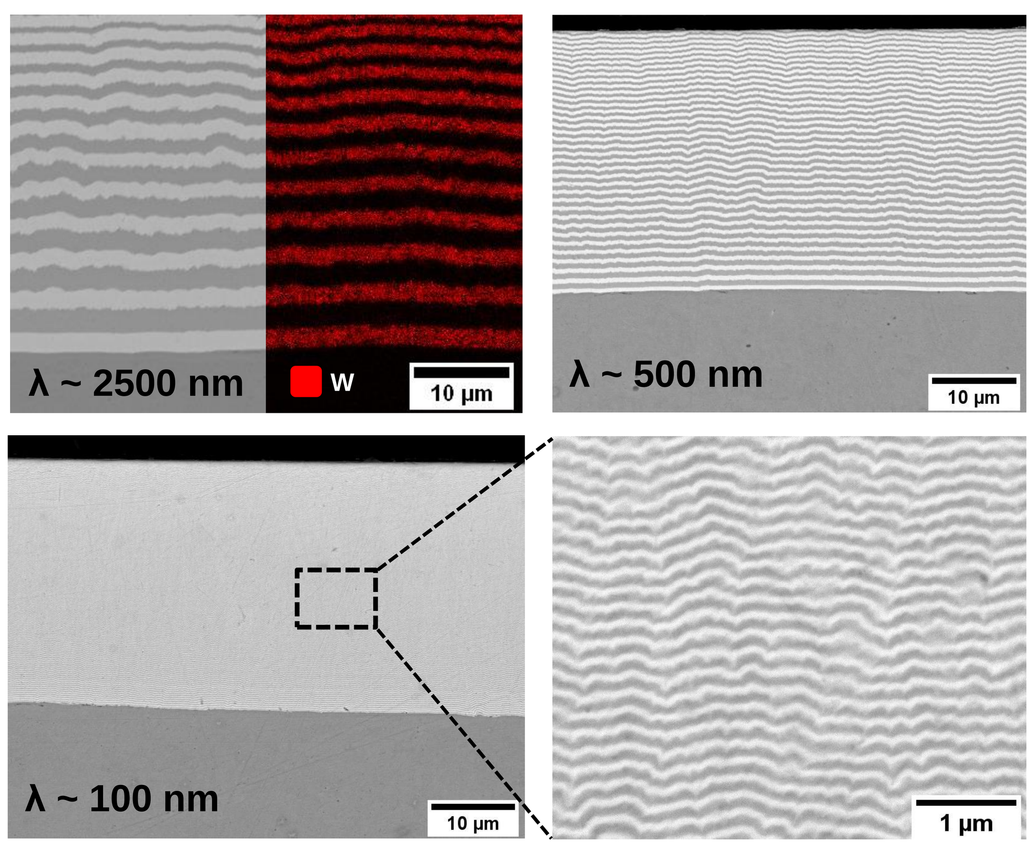



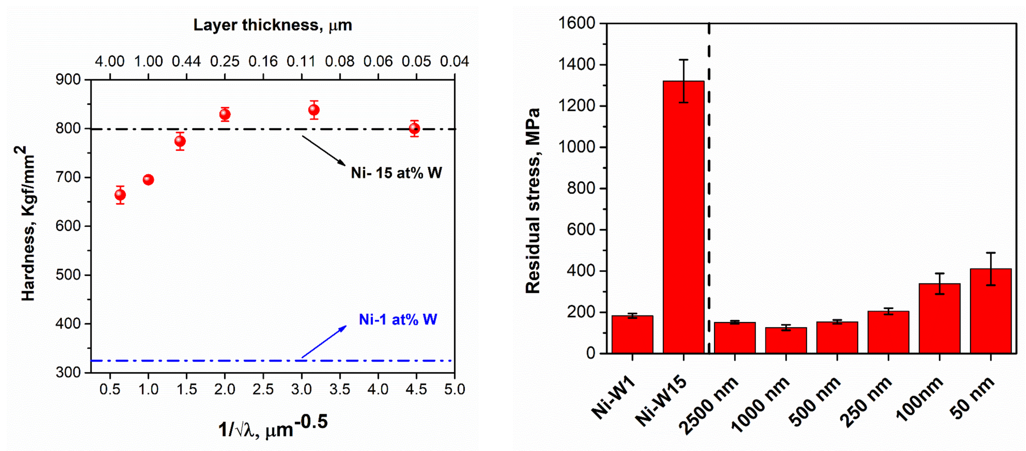

- The microstructural (crystallite size) and mechanical (hardness) properties are evaluated as a function of depth.
- Gradient in W-content has resulted in microstructural and mechanical property gradients.
- Compositional gradient Ni-W: substantial reduction (~ 40%) in the residual stress compared to homogeneous Ni-W.

### ➢ Ni-W multilayers



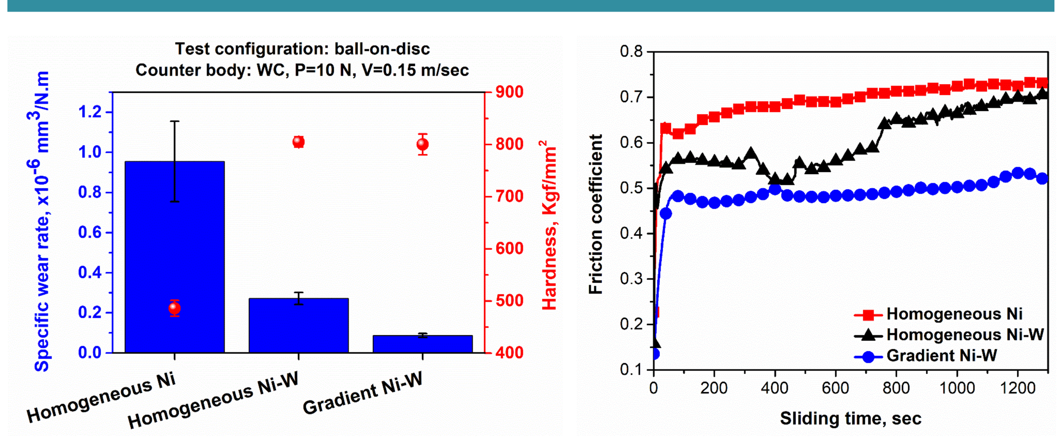

- Grain size: Ni-W1: ~1 ± 0.4 µm, Ni-W15: 8 ± 2 nm.
- Pulse reverse current electrodeposition: Enables to access wide range of grain sizes in Ni-W alloys.

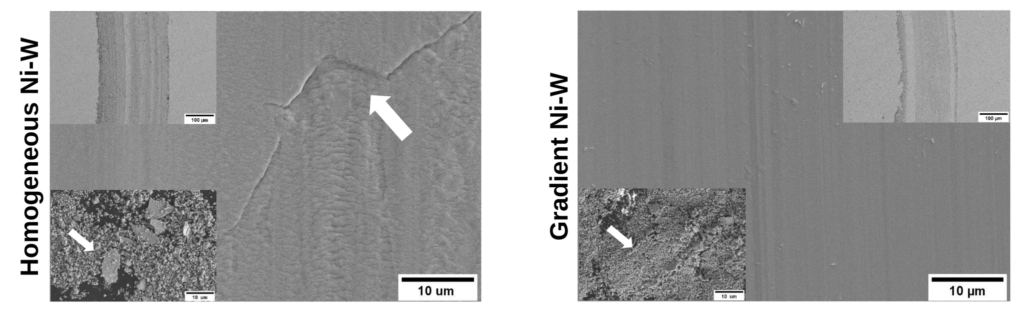


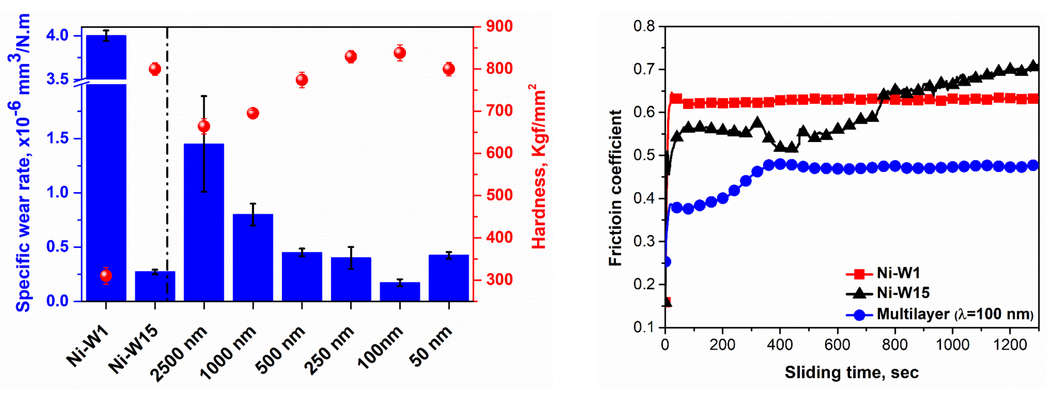

## Results: Wear performance

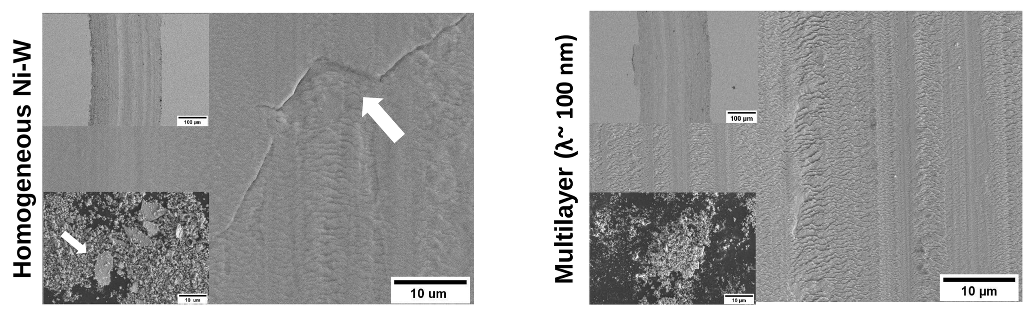
### ➢ Continuous gradient Ni-W




### ➢ Ni-W multilayers

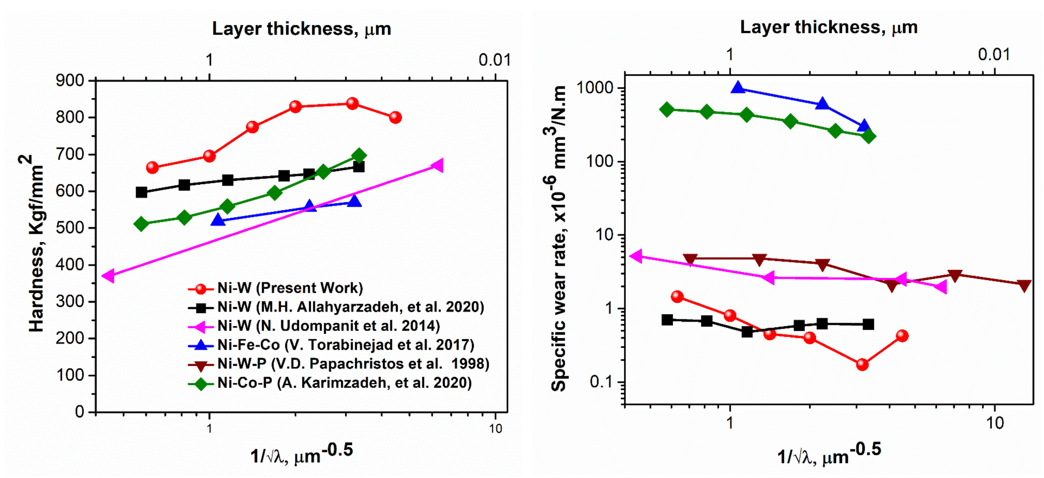



- Comparing with their homogeneous counterparts, both continuous gradient and multi-layered Ni-W coatings have demonstrated superior wear resistance and lower friction coefficients.

## Discussion

- Wear induced delamination and cracking is suppressed in case of continuous gradient and multilayer Ni-W coatings as confirmed by the post analysis of wear track and wear debris.
- The substantial reduction in the residual stresses may have reduced the severity of stresses generated during sliding contact.
- The performance of Ni-W multilayers is compared with literature and shows their superior wear resistance.




## Conclusions

- For continuous gradient, the bath chemistry is judiciously tuned to tailor the W-content along the growth direction.
- While, for multilayers, the effect of reverse/anodic current is exploited to deposit layers with extreme W-contents.
- In Ni-W multilayers, sandwiching the hard and soft layers has resulted in substantial reduction in residual stresses. A similar effect is observed in continuous gradient Ni-W due to a smooth transition in grain size across interface.
- Both the gradient coatings have shown superior wear resistance compared to homogeneous counterparts.
- Gradient nanocrystalline coatings: open new avenues for developing strong and tough coatings.


## Contact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## References


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