High-Performance Metal-ceramic Hybrid Coatings for Extreme Conditions

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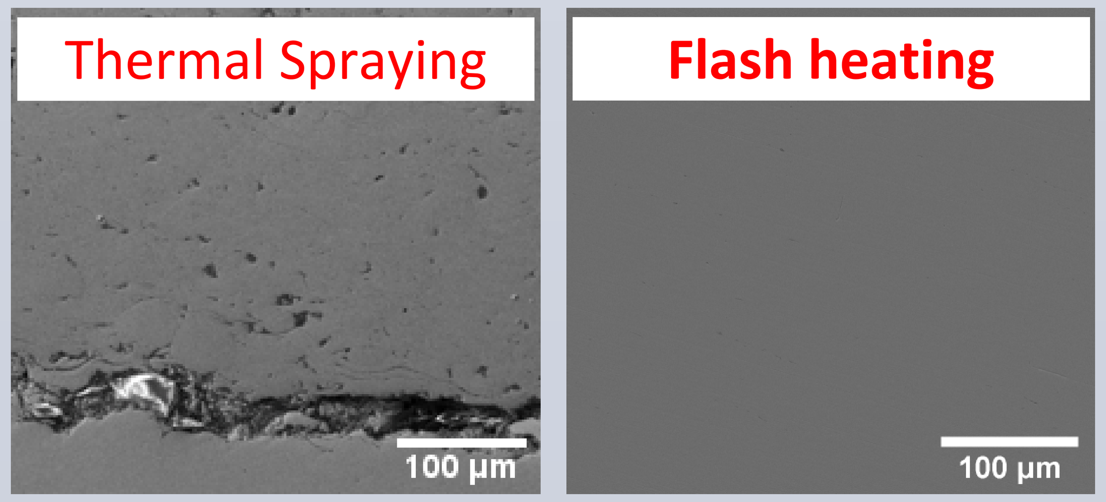
Abstract

One of the challenges in producing conventional coatings is to reduce the porosity. Porosity affects coating properties and weakens adhesion between coating and substrate. As such, this research introduces an alternative approach which we have developed known as flash heating. This process uses plasma-induced heat transfer to selectively bond powder to a substrate. Ni-SiC coatings were developed for wear and hardness performance. These coatings have high melting points, but due to the localization of the heat input the coatings can be applied to lower melting point materials such as carbon steels without affecting the substrate. The substrate used was an ASTM A759 (quenched) carbon steel due to its high hardness and good wear performance. Results showed that the hardness in the coatings was increased by 121% compared to the substrate. Meanwhile, wear rate was reduced by as much as 80% in the coatings with respect to the substrate when an Al_2O_3 counterpart was used. Pure SiC coatings were also fabricated to show some limitations of this flash heating technique. The SiC coatings showed Fe diffusion from the substrate during coating fabrication which reduced the coating performance compared to the Ni-SiC coatings.

Introduction

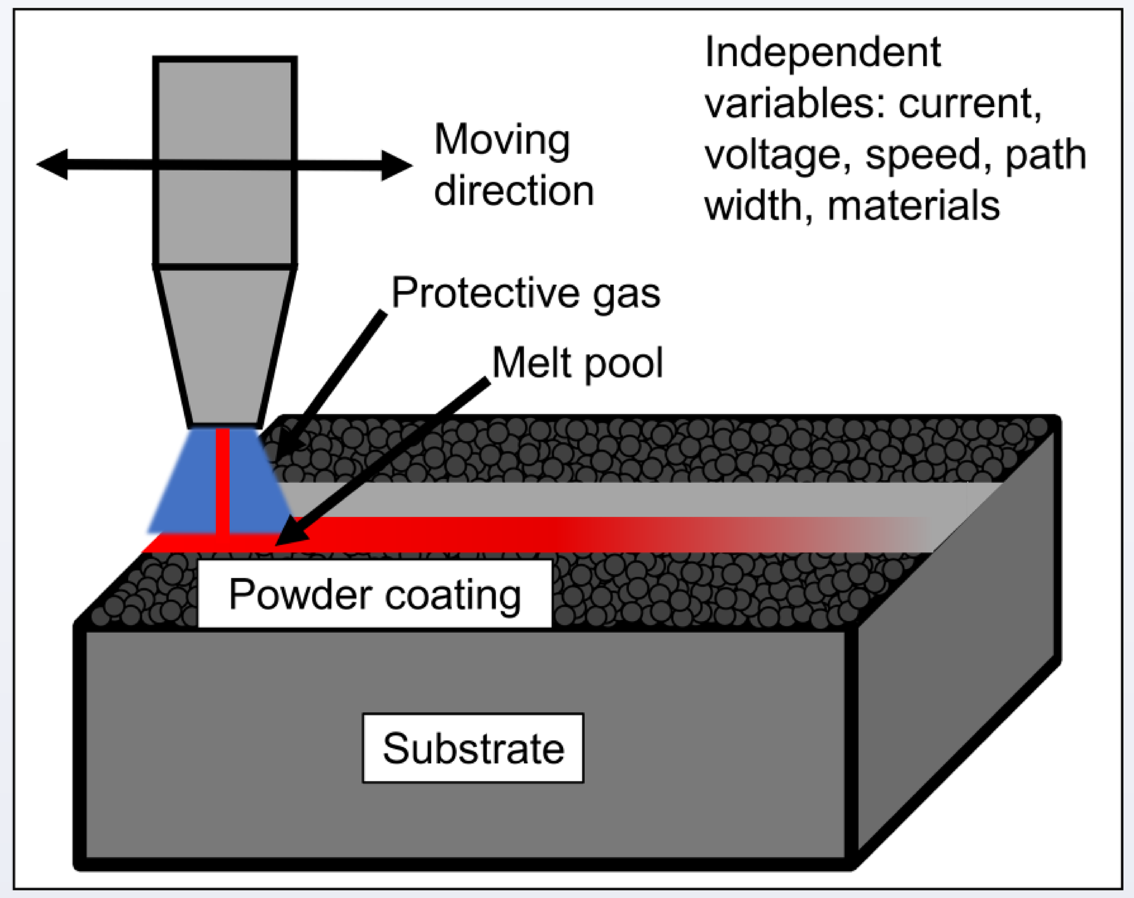
There are several techniques used to fabricate ceramic-metallic composite coatings such as Ni-SiC coatings. One of the more common methods is electrodeposition. However, SiC particles dispersed in the bath fluid can cause uneven deposition in the coating, and maximum SiC content depends on particle size. Additionally, SiC particles are not easily embedded in the coating, meaning Ni-SiC coatings typically have a low concentration of SiC particles, usually in the range of 5 wt.%. This technique also results in reduced hardness compared to other techniques such as thermal spraying. While thermal spraying can also be used to fabricate Ni-SiC coatings, it has some issues as well. The bonding which occurs is mostly mechanical. Additionally, thermal spraying techniques require large spraying distances to improve coating adhesion, but this can cause particles to cool and even solidify, resulting in high coating porosity. Thermal spraying techniques can also be cost inefficient due to waste material.

As such, there is a need for a coating technique which does not have limitations on composition like electrodeposition while creating metallurgically bonded, low porosity, cost efficient coatings over a wide range of thicknesses. As seen below, the technique developed in this research creates coatings with much lower porosity than thermal spraying techniques, and additionally results in no waste material.



- Comparison between commercial thermal coating technology[1] and the new flash heating technique (developed in this research)

Proposed setup



- The flash heating procedure

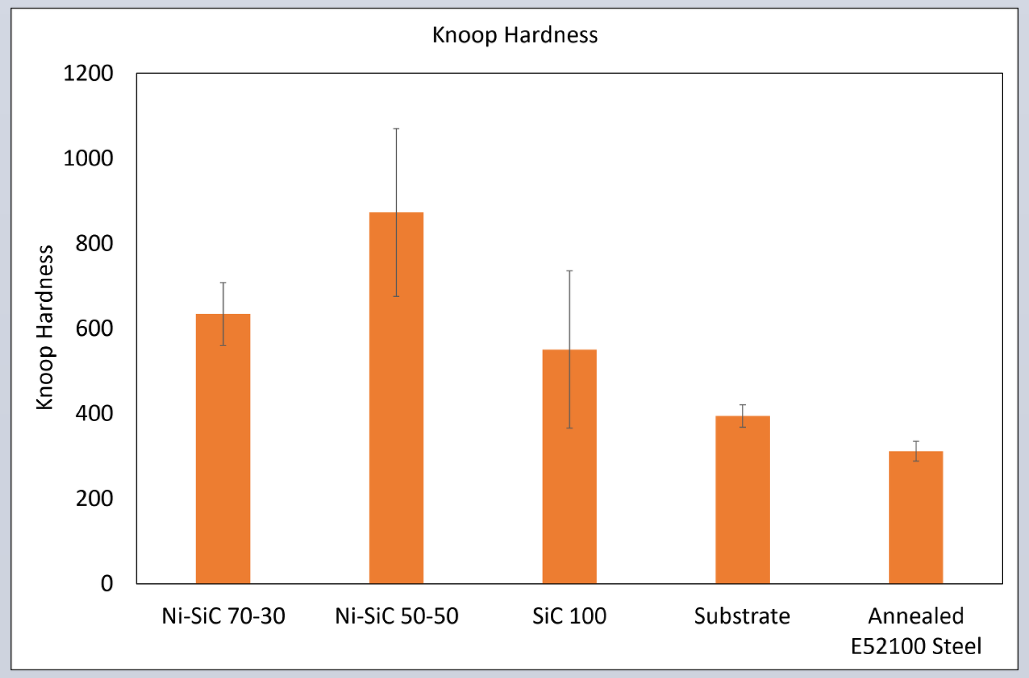
Materials and Method

Materials
- Coating compositions:
    - Ni-SiC 70-30 (wt.%)
    - Ni-SiC 50-50 (wt.%)
    - SiC
- Substrate: ASTM A759 (quenched) carbon steel

Fabrication
- Flash heating parameters:
    - Plasma current: 110 A
    - Electrode separation distance: 3 mm
    - Ionizing gas: argon
    - Gas flow rate: 15 cfh

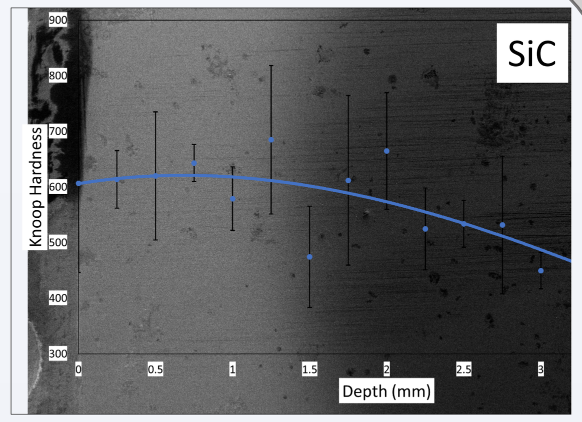
Characterization
- Tribotesting
- Knoop hardness testing
- Interferometry
- Scanning electron microscopy
- Energy dispersive X-ray spectroscopy

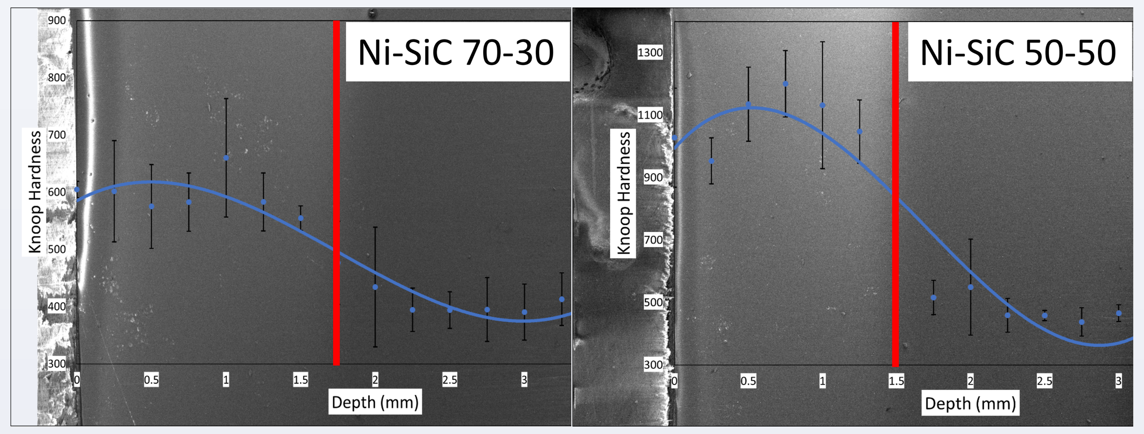
Results & Discussion



- Coatings greatly improved surface hardness compared to high hardness carbon steel substrate (ASTM A759 quenched)

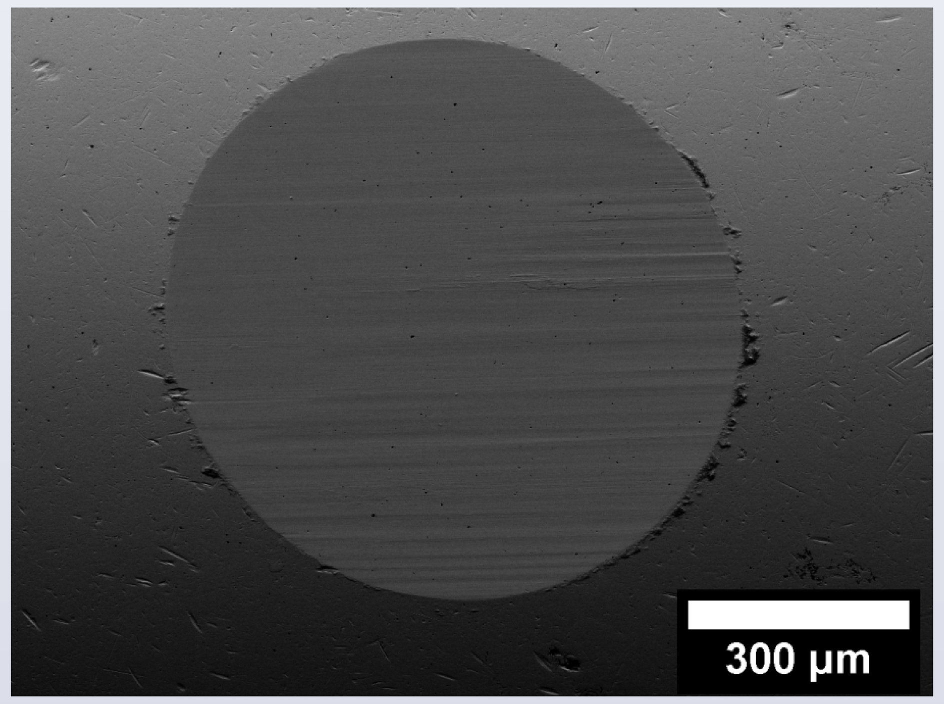
Cross section hardness profiles showed that when Ni is added to SiC, there are distinct regions of coating and substrate (separated by the red line).



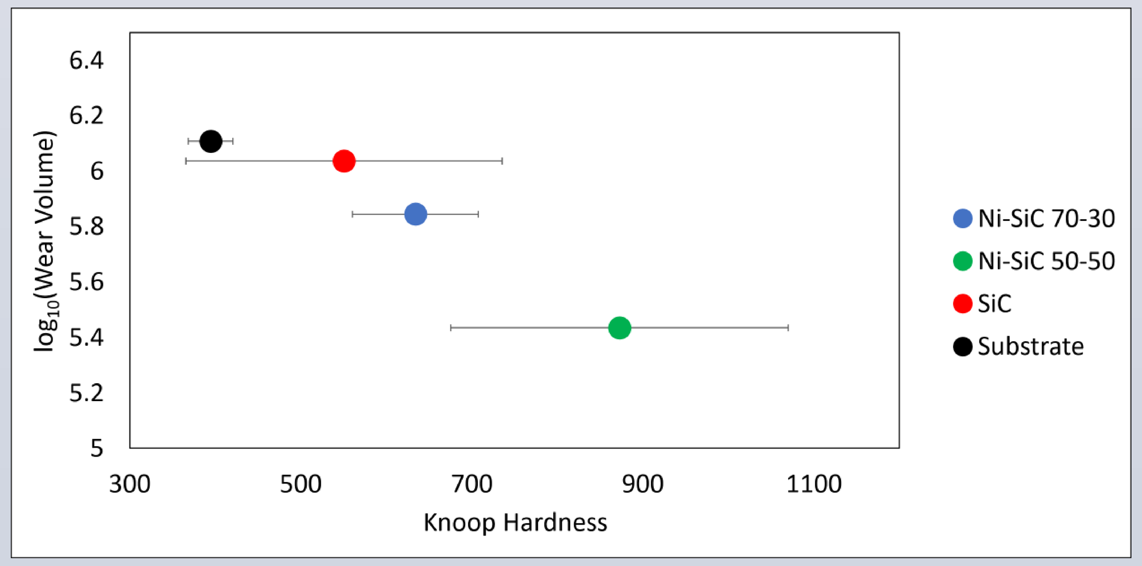


- Scanning electron microscopy images of the cross sections of each coating, with their hardness profile overlayed

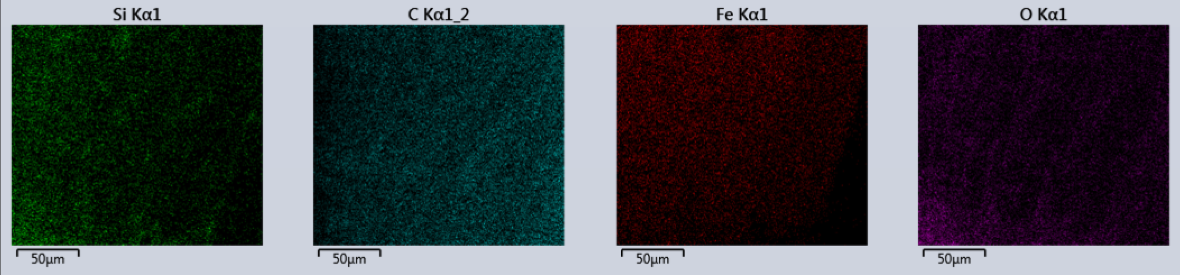
Surface of a cold-worked E52100 bearing steel ball after tribotesting against Ni-SiC coatings



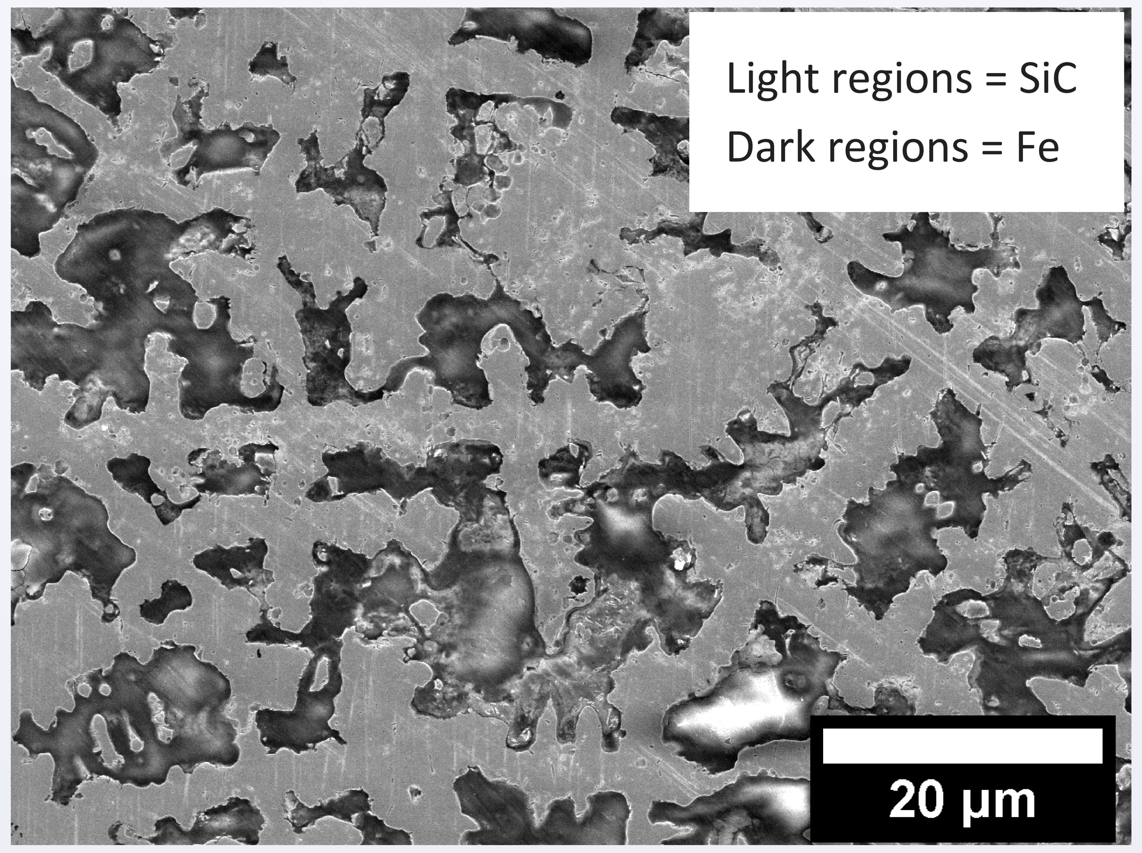
- Ni-SiC coatings experienced no abrasive wear after 10,000 cycles, instead the counterpart experienced severe wear



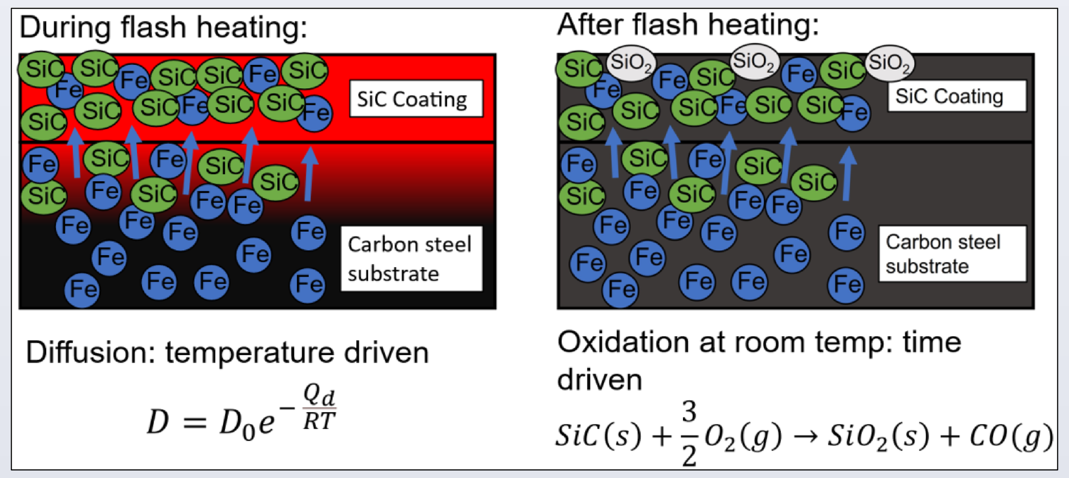
- When using an Al_2O_3 counterpart, wear resistance in Ni-SiC coatings was reduced due to increased hardness



- Energy dispersive X-ray spectroscopy maps of the SiC coating showed presence of iron (diffusion) and oxygen (oxidation)



- Scanning electron microscopy showed microstructure of SiC and Fe. Presence of Fe decreased performance of SiC coating.



$$D = D_0 e^{-\frac{Q_d}{RT}}$$

$$SiC(s) + \frac{3}{2}O_2(g) \rightarrow SiO_2(s) + CO(g)$$

- Diffusion occurs during fabrication (temperature driven), while oxidation occurs over time after fabrication (time driven)

Conclusions

- Ni-SiC coatings improved hardness by as much as 121% and decreased wear rate by as much as 80%
- 1.5 mm thick coatings showed distinct hardness change at coating-substate interface
- Substrate hardness not influenced from coating fabrication
- SiC coating had limited performance due to Fe diffusion and surface oxidation

References

1) Dong et al., *J. Eng. Mat. Tech.*, 2018
2) Renner et al., *IMECE Proceedings*, 2021
3) Renner et al., *Lubricants*, 2022
4) Renner et al., *Surf. Coat. Tech.*, 2022

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