

M. High-Density Infrared Surface Treatment of Materials for Heavy-Duty Vehicles

T. N. Tiegs, F. C. Montgomery, D. C. Harper, J. O. Kiggans, and C. A. Blue
Oak Ridge National Laboratory
P.O. Box 2008, MS-6087
Oak Ridge, TN 37831-6087
(865) 574-5173; fax: (865) 574-4357; e-mail: tiegstn@ornl.gov

DOE Technology Development Area Specialist: James J. Eberhardt
(202) 586-9837; fax: (202) 586-1600; e-mail: james.eberhardt@ee.doe.gov
ORNL Technical Advisor: D. Ray Johnson
(865) 576-6832; fax: (865) 574-6098; e-mail: johnsondr@ornl.gov

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Objectives

- Use high-density infrared (HDI) technology to produce corrosion and/or wear resistance coatings on metal substrates.
- Use lighter or more cost-effective bulk materials with coatings applied to surfaces where improved properties required.

Approach

- Examine a couple of approaches on surface modification that would be of interest to materials for heavy-duty vehicles.
- Examine the application and formation of adherent, wear/corrosion-resistant coatings.
- Base the initial tests on hard metal compositions applied onto iron-based parts that are currently used in diesel engines.

Accomplishments

- Determined that plain hard metal coatings without binder additions have a very narrow window of HDI process conditions and are not practical on a large scale.
- Correlated coating process parameters (compositions, HDI parameters) with coating microstructural development.

Future Direction

- Investigate the coating of complex shaped parts by HDI technology.
- Determine potential for producing wear-resistance diffusion coatings for heavy-duty vehicle applications.

Introduction

High-density infrared (HDI) technology is relatively new to the materials processing area and is gradually being exploited in materials processing.

The HDI processing facility at Oak Ridge National Laboratory utilizes a unique technology to produce extremely high-power densities of up to 3.5 kW/cm² with a single lamp. Instead of using an electrically

heated resistive element to produce radiant energy, a controlled and contained plasma is utilized.

Because the technology is relatively new, its utility to the surface treatment of materials for applications in heavy-duty vehicles is being explored. In most cases, the need for wear resistance, or corrosion resistance, or high strength is only necessary in selected areas of the part that is exposed to the working environment or under high stress. Therefore, it would be desirable to use materials that are lighter or less expensive for the bulk of the part and only have the appropriate surface properties where required. In addition, the HDI approach would be more cost-effective than other competitive processes such as physical vapor deposition.

Non-line-of-sight coatings are of interest for application on heavy-duty vehicle parts, such as gears. Pack cementation is an industrial process currently used to apply diffusion coatings onto metal parts. Other research has shown that microwave heating can be used to produce superior diffusion coatings with alloying additives such as aluminum, silicon, and boron. The project will examine the potential to produce wear-resistance diffusion coatings by both HDI technology and microwave pack cementation.

Results

Earlier work had shown that adherent coatings of hard metal compositions could be applied to a variety of metal substrates (D2 tool steel, 4140 alloy steel, and cast iron). However, a problem with the earlier coatings was that a preheat step was required to minimize sintering of the slurry coating prior to bonding with the substrate. When the slurry coating was heated too fast, it tended to peel off from the substrate and crack. The preheating step allowed the substrate to get hot enough so bonding occurred.

Samples were fabricated that used either WC or TiC particles only for the coating. The sintering temperature for these plain carbides is significantly higher than the melting point of the substrates. Consequently, because no binder additions (i.e., Ni or Ni₃Al) will be present, sintering and cracking will be inhibited. This will allow the coating to heat up to a sufficiently high temperature so that the underlying substrate will melt and be wicked into the coating by capillary action. Previous work has shown that

WC-cast iron composites have excellent wear behavior, so these will be the initial compositions.

Samples were fabricated with varying coating thickness (50 and 100 μm) and particle type (WC, TiC, W, or WC/W). The samples were infrared (IR) treated at numerous exposure conditions. Cracking of the coatings was observed in a similar behavior to previous tests where the binder was included. A pre-heat step helped to minimize the cracking. However, getting the coatings hot enough to melt the underlying substrate was extremely sensitive. The conditions to go from little bonding to where extensive melting of the entire sample occurred were very narrow. Control of the coating process without the incorporation of binder particles in the coating is very difficult.

Additional examinations of coatings with binders was done to correlate coating process parameters with coating microstructural development. Some of the parameters included substrate composition, binder chemistry, ceramic particle type, and HDI heating cycles. Previous results had shown excellent wear resistance for coatings having Ni₃Al as the binder in the hard metal coating. Consequently, most of the correlations were done with these coating types.

Examples of WC-Ni₃Al coatings on substrates of D2 tool steel, 4140 alloy steel, and cast iron are shown in Figures 1–3, respectively. The coatings are much thicker than the intended $\sim 100\ \mu\text{m}$, indicating significant mixing with the underlying substrate. A penetration zone of Ni₃Al into the D2 tool steel was significant ($\leq 100\ \mu\text{m}$), whereas only a minor reaction layer ($\sim 10\ \mu\text{m}$) was observed at the interface on the 4140 alloy steel. No reaction layer was evident with the cast iron substrate; however, there appeared to be a diffuse mixing zone within the coating. In addition, the cast iron had graphite precipitates throughout the coating which were more pronounced adjacent to the interface. Some grain growth of the WC was observed at the interface between the coating and the D2 tool steel. Conversely, more uniform grain sizes were observed across the coatings on the 4140 alloy steel and the cast iron. Note that, in general, the grain sizes were on the order of the initial starting particle sizes, indicating little to no grain growth during the HDI thermal treatments.

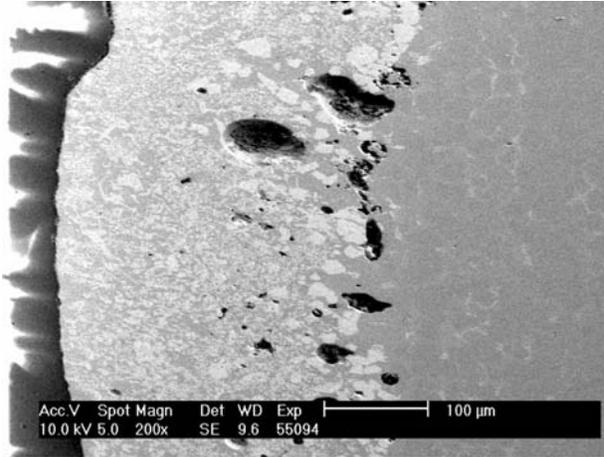


Figure 1. Cross-section of WC-Ni₃Al coating on D2 tool steel. The coating was initially intended to be 100 μm thick. Coating bonded by HDI thermal treatment using a 4-cm defocus setting and lamp parameters of 0 to 300 amps in 5 min (preheat), followed by 900 amps for 3.5 s for bonding.

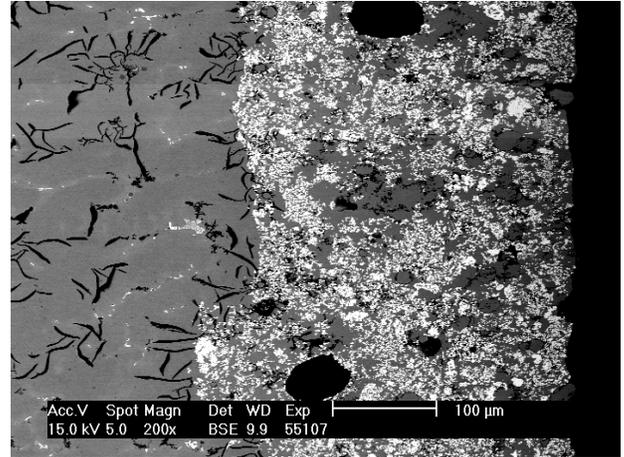


Figure 3. Cross-section of WC-Ni₃Al coating on cast iron. The coating was initially intended to be 100 μm thick. Coating bonded by HDI thermal treatment using a 4-cm defocus setting and lamp parameters of 0 to 300 amps in 5 min (preheat), followed by 900 amps for 3.5 s for bonding.

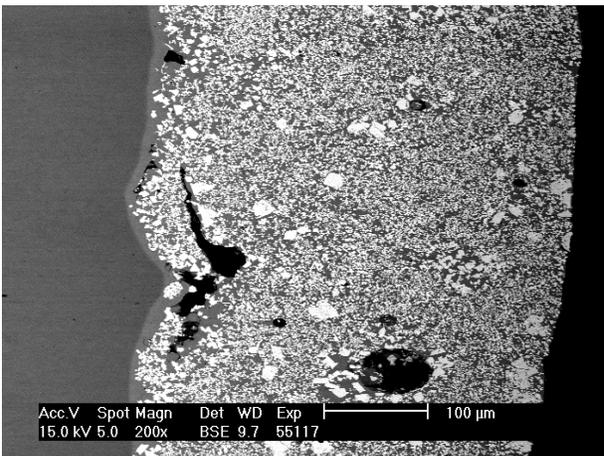


Figure 2. Cross-section of WC-Ni₃Al coating on 4140 alloy steel. The coating was initially intended to be 100 μm thick. Coating bonded by HDI thermal treatment using a 4-cm defocus setting and lamp parameters of 0 to 300 amps in 5 min (preheat), followed by 900 amps for 3.5 s for bonding.

A cross-section of a WC-Co coating on D2 tool steel is shown in Figure 4. Less penetration of the Co into the D2 tool steel ($\sim 25 \mu\text{m}$) compared to the Ni₃Al was evident. Less mixing between the coating and the substrate resulted in a uniform grain size across the coating.

When TiC (with Ni₃Al) was used for the coating there appeared to be less penetration of the Ni₃Al into the D2 tool steel substrate (Figure 5). This needs to be confirmed with additional characterization. Normally, TiC grains are quite faceted; however, the TiC grains in the coating were rounded, indicating alloying of the Ni₃Al binder with iron from the substrate. In addition, no core-rim structures, which are typically observed with TiC grains in Ni₃Al, were evident. This indicates only minimal dissolution and reprecipitation of the TiC during melting of the coating. Like the WC-based materials, the final grain size was similar to the starting TiC particle size.

The effect of the use of multiple HDI treatments on the microstructure of a WC-Ni₃Al coating on D2 tool steel is shown in Figure 6. The major effect of the double treatment was to minimize bubbles in the

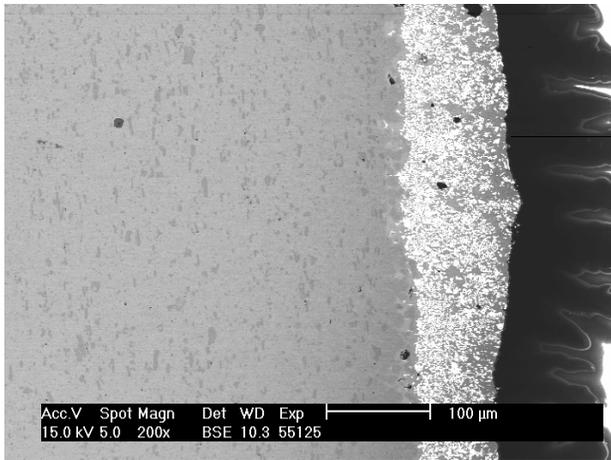


Figure 4. Cross-section of WC-Co coating on D2 tool steel. The coating was initially intended to be 100 μm thick. Coating bonded by HDI thermal treatment using a 4-cm defocus setting and lamp parameters of 0 to 300 amps in 5 min (preheat), followed by 1000 amps for 3.5 s for bonding.

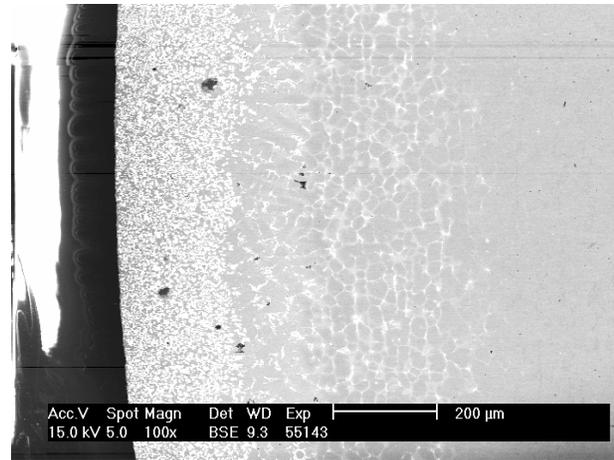


Figure 6. Cross-section of WC-Ni₃Al coating on D2 tool steel. The coating was initially intended to be 100 μm thick. Coating bonded by HDI thermal treatment using a 4-cm defocus setting and lamp parameters of 0 to 400 amps in 5 min (preheat), followed by 900 amps for 2 s and 900 amps for 1 s for bonding. There was approximately 15 s between high-energy exposures.

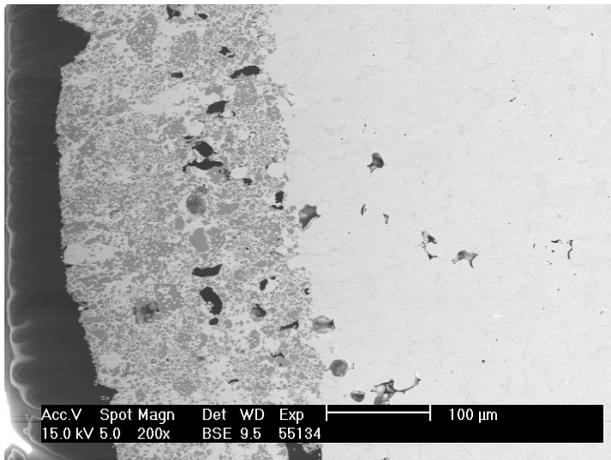


Figure 5. Cross-section of TiC-Ni₃Al coating on D2 tool steel. The coating was initially intended to be 100 μm thick. Coating bonded by HDI thermal treatment using a 4-cm defocus setting and lamp parameters of 0 to 400 amps in 5 min (preheat), followed by 900 amps for 2 s and 900 amps for 1 s for bonding. There was approximately 15 s between high-energy exposures.

coating. It is hypothesized that during the second HDI exposure, the coating is remelted and any trapped bubbles can be released. However, the double treatment increases penetration of the Ni₃Al into the D2 tool steel from ~100 μm for a single exposure to ~300 μm for the multiple heating. The WC grain size was also increased by the second HDI heat treatment.

Conclusions

It was determined that plain hard metal coatings without binder additions have a very narrow window of HDI process conditions and are not practical on a large scale. Significant interactions and mixing occur between the coatings and the underlying substrates. In most cases, little to no grain growth by WC or TiC was observed during HDI heat treatments.

Presentations and Publications

T. N. Tiegs, “High Density Infrared Surface Treatment,” at the Heavy Vehicles Materials Peer Review, Oak Ridge, Tennessee, September 13–15, 2005.