ATTRIBUTES OF NANOSTRUCTURED MCrAlYs

George E. Kim, Ph.D.

CSAT

June 23, 2015

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OVERVIEW:

- cryogenically milled NiCrAlY bond coat
- non-cryogenically milled NiCrAlY bond coat
- possible mechanisms
- potential for cold spray
- summary
- acknowledgements

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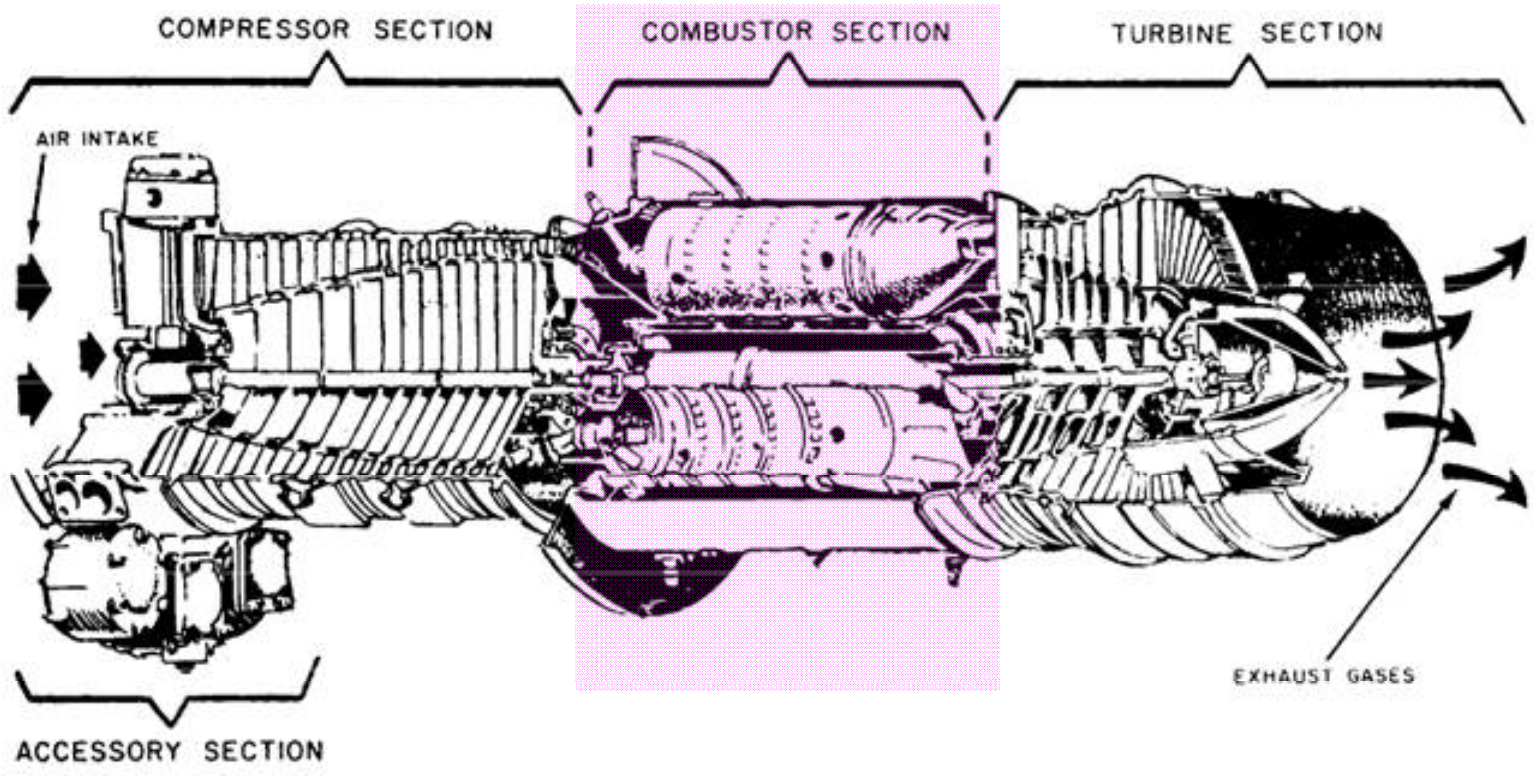
gas turbine engine



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n-NiCrAlY Bond Coats using Cryomilled Powder

George E. Kim

Julie Schoenung et al.

Virgil Provenzano

Supported by United States Office of Naval Research (Contract no. N00014-03-10146)

Dr. Lawrence T. Kabacoff – Program Officer

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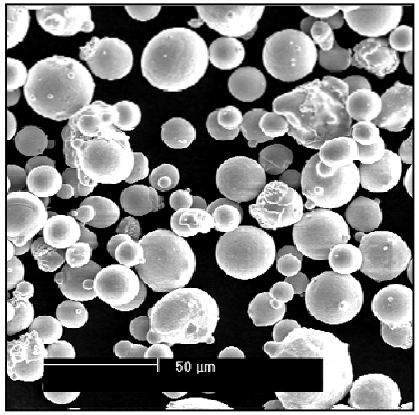
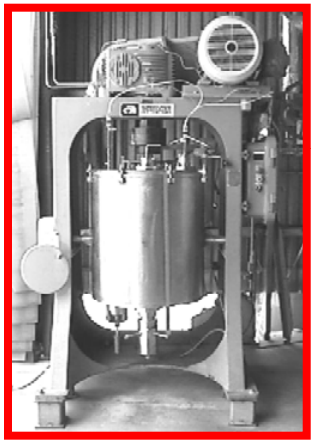
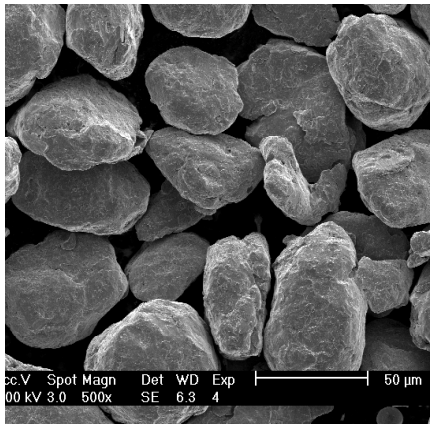
powder processing

cryomilled with
0.635 cm SS balls
for 8 hours







conventional NiCrAlY powder

- **avg. particle size: 30 µm**
- **avg. grain size: 1-5 µm**

cryomilled NiCrAlY powder

- **avg. particle size: 35 µm**
- **avg. grain size: 27 nm**

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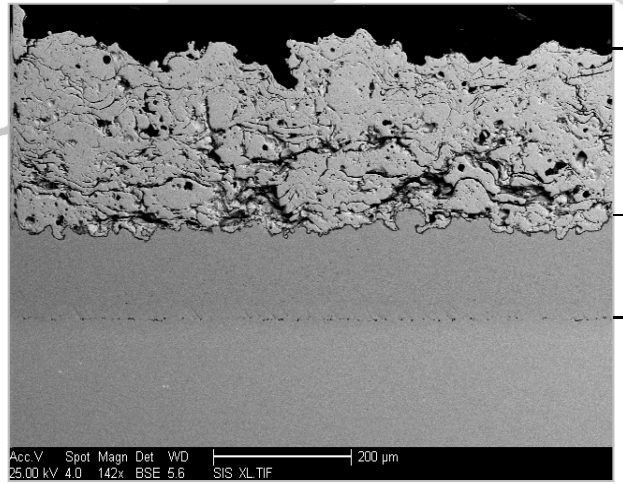
thermal cycle test

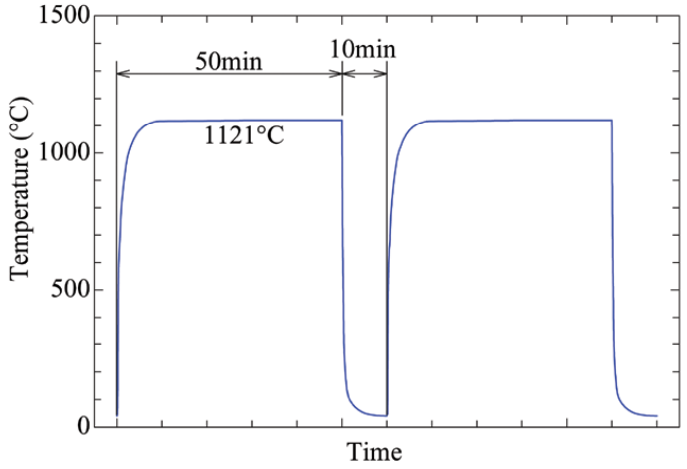


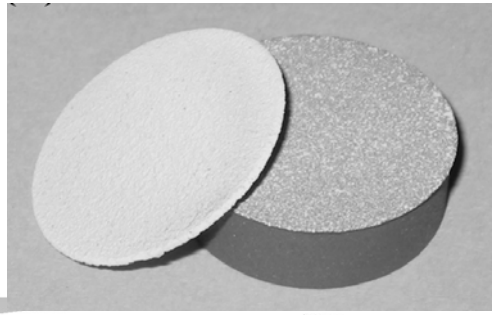
APS YPSZ top coat
250 - 300 µm

HVOF or LPPS bond coat
100 -150 µm

substrate

Some samples were heat treated at 1080°C in vacuum for 4h before thermal cycle testing.





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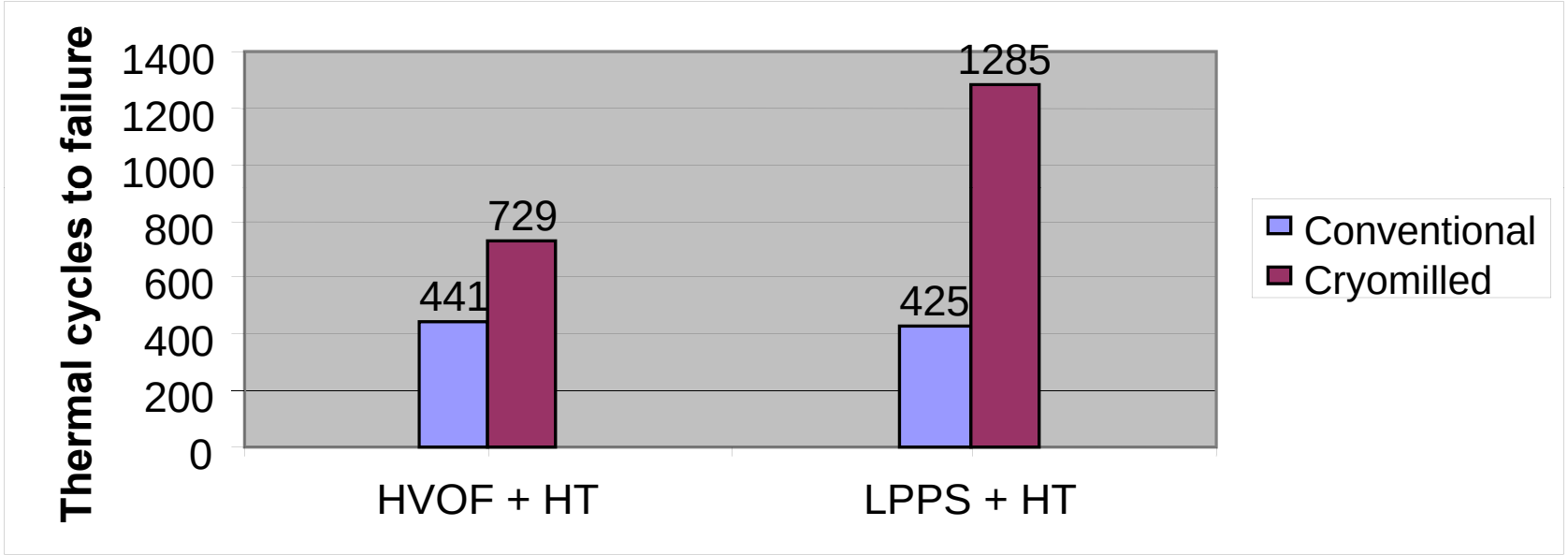
thermal cycling test



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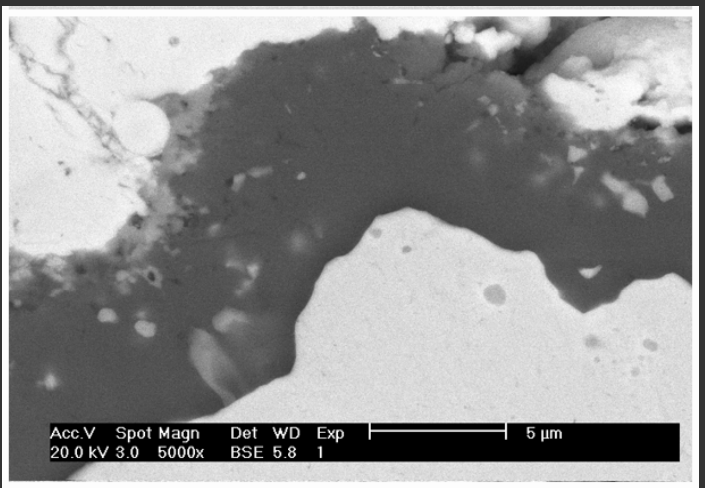
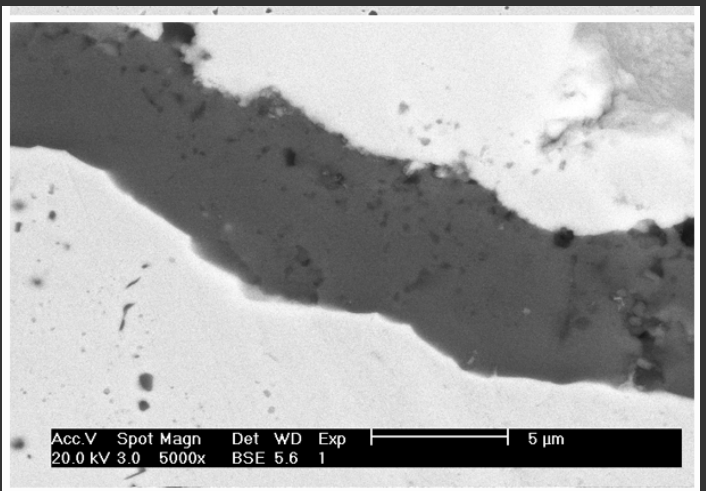
HTed TBCs with LPPS bond coat

Conventional



LPPS B 425 cycles

Cryomilled



LPPS D 1285 cycles

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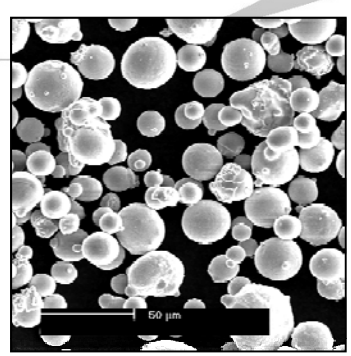
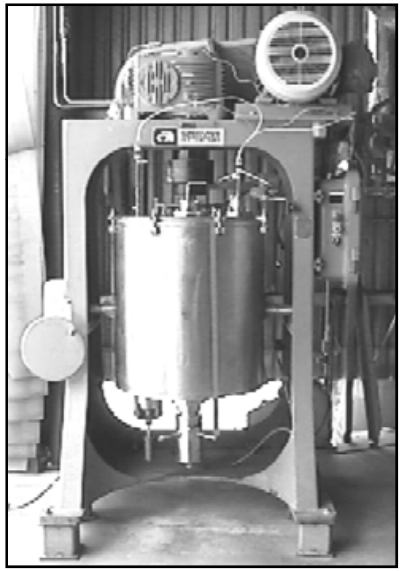
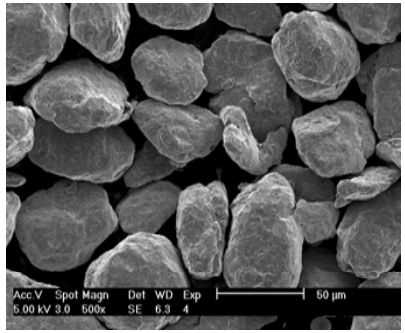
cryomilling processing







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n-NiCrAlY Bond Coats using Non-cryogenically Milled Powder

George E. Kim **Tony Addona** **Mathieu Brochu**

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OBJECTIVE:

"To develop an economically viable nanostructured bond coat with superior protective/performance properties"

Emphasis on:

- **processing of nanostructured, equiaxed NiCrAlY powder using non-cryogenic milling that provides enhanced attributes similar to those observed in cryomilled powder**

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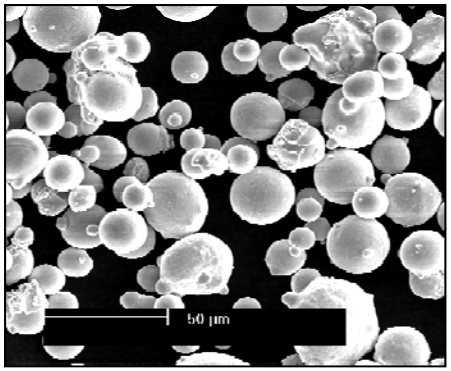
non-cryogenic milling: lower cost processing of n-metal powder

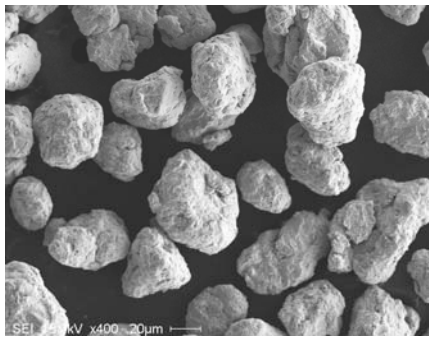
Partially supported by United States Office of Naval Research (Contract no. N00014-03-10146)

Dr. Lawrence T. Kabacoff – Program Officer

as-received

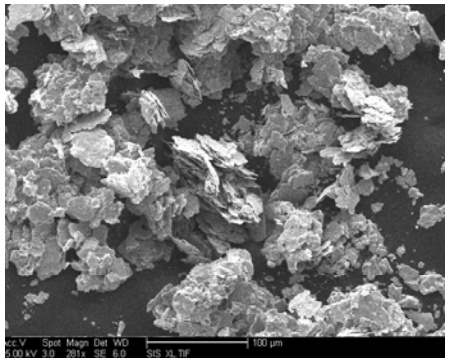


3.5 years

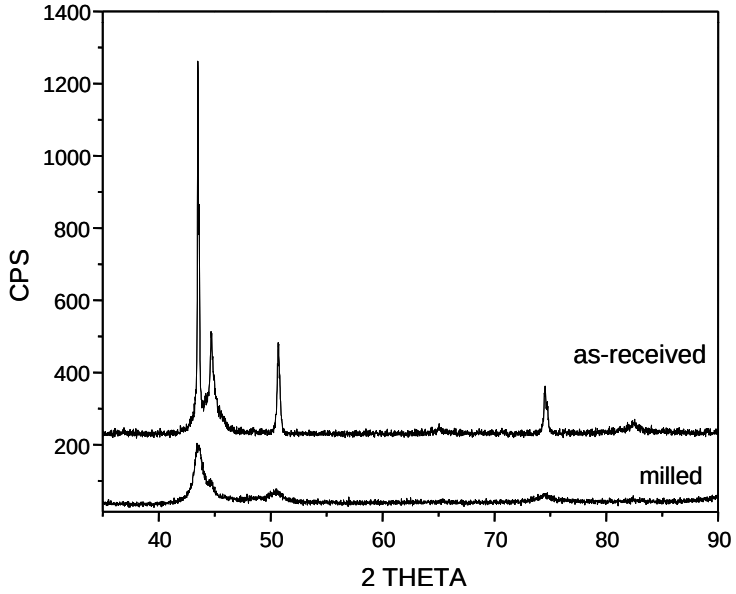


current powder

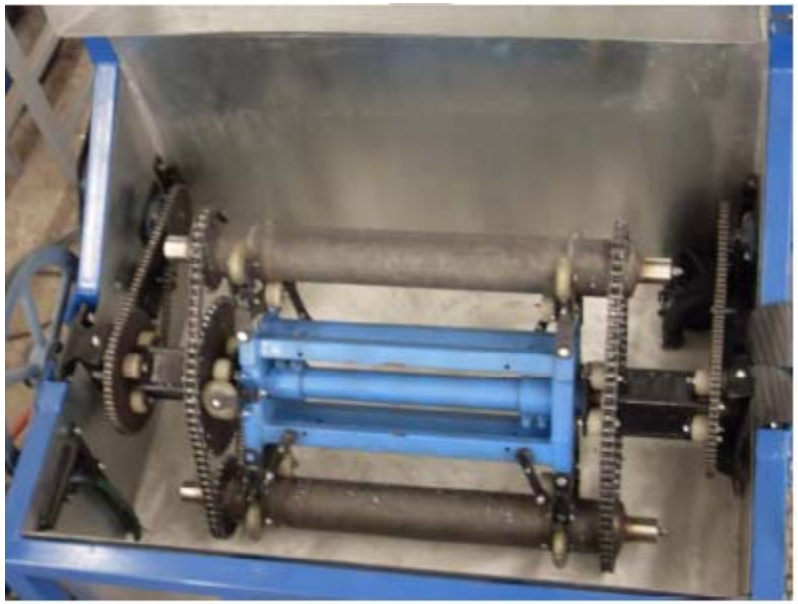
in 2007



flake particles



non-cryogenic milling: scale-up

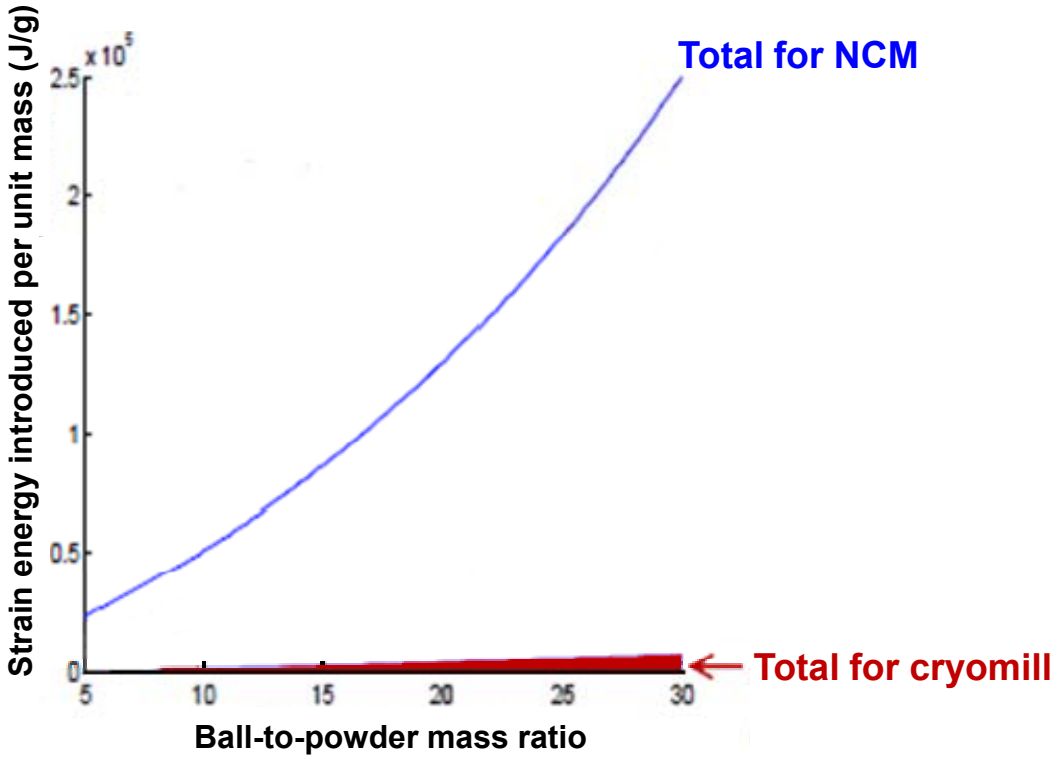


MCrAlY powder

2nd Generation
(4’ x 6’ x 3’ and 800 lb)
- **5 lb batch**
- **$ 1,000/lb**
- **500 lb/yr capacity**

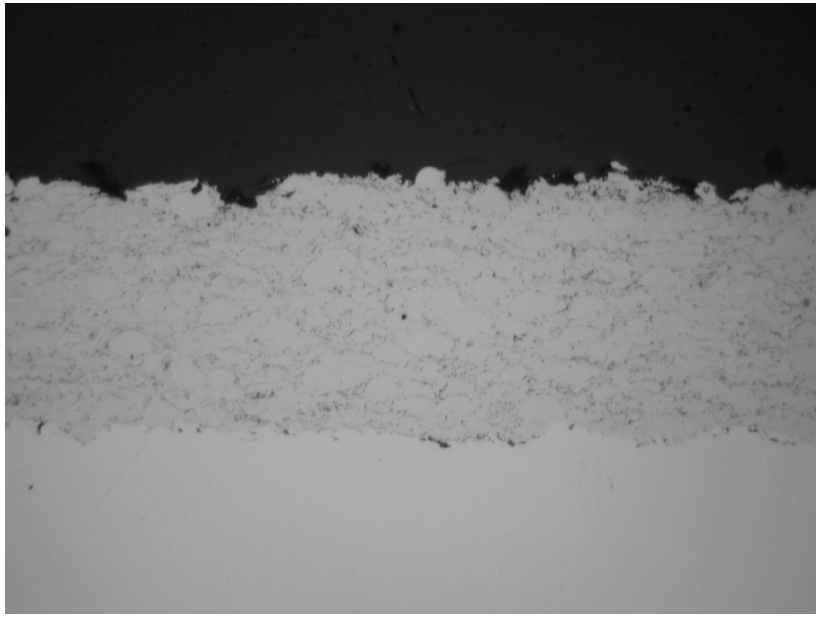
3rd Generation ***(provisional patent)***
(8’ x 8’ x 10’ and 10,000 lb)
- **100 lb batch**
- **< $ 50/lb**
- **20,000 lb/yr capacity**

strain energy comparison



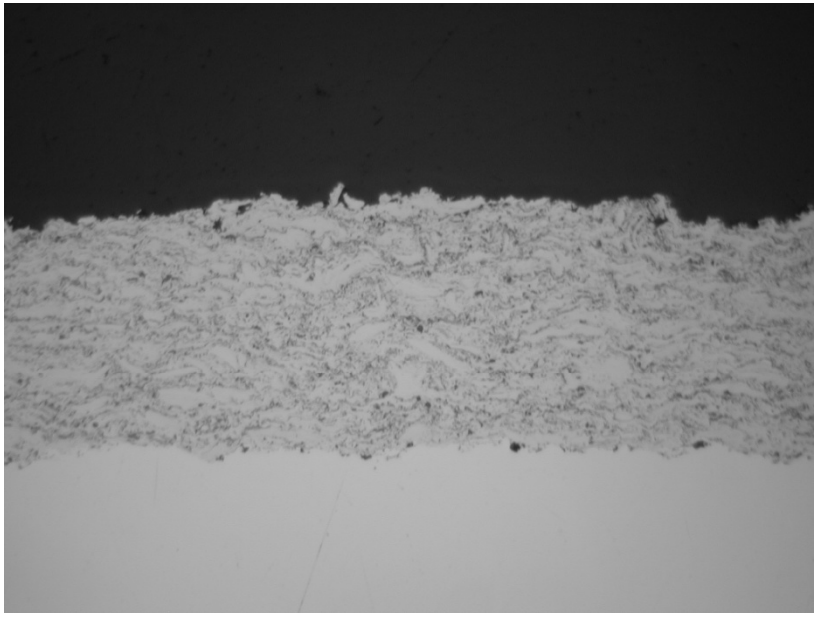
HVOF applied NiCrAlY coatings

conventional



- **515 $HV_{0.3}$**
- **< 0.5% porosity**

nanostructured



- **522 $HV_{0.3}$**
- **< 0.5 % porosity**

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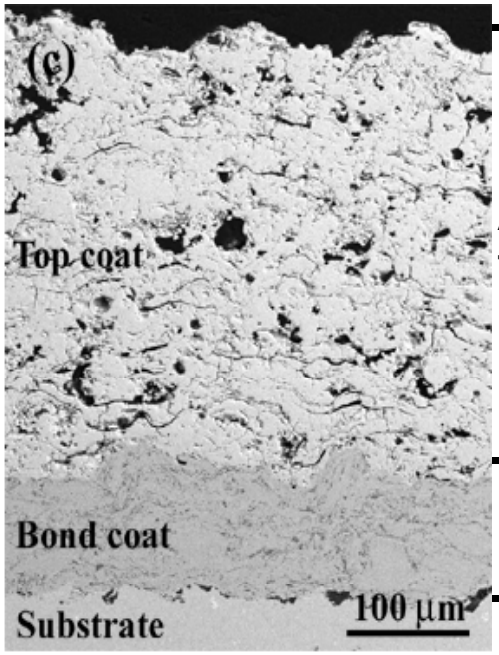
thermal cycling test



APS YPSZ top coat

HVOF NiCrAlY bond coat

- **each cycle consisted of 9 min ramp up, 45 min hold at 1,093 °C, followed by a 10 min forced air cool down**

Samples were not heat treated before thermal cycle testing.

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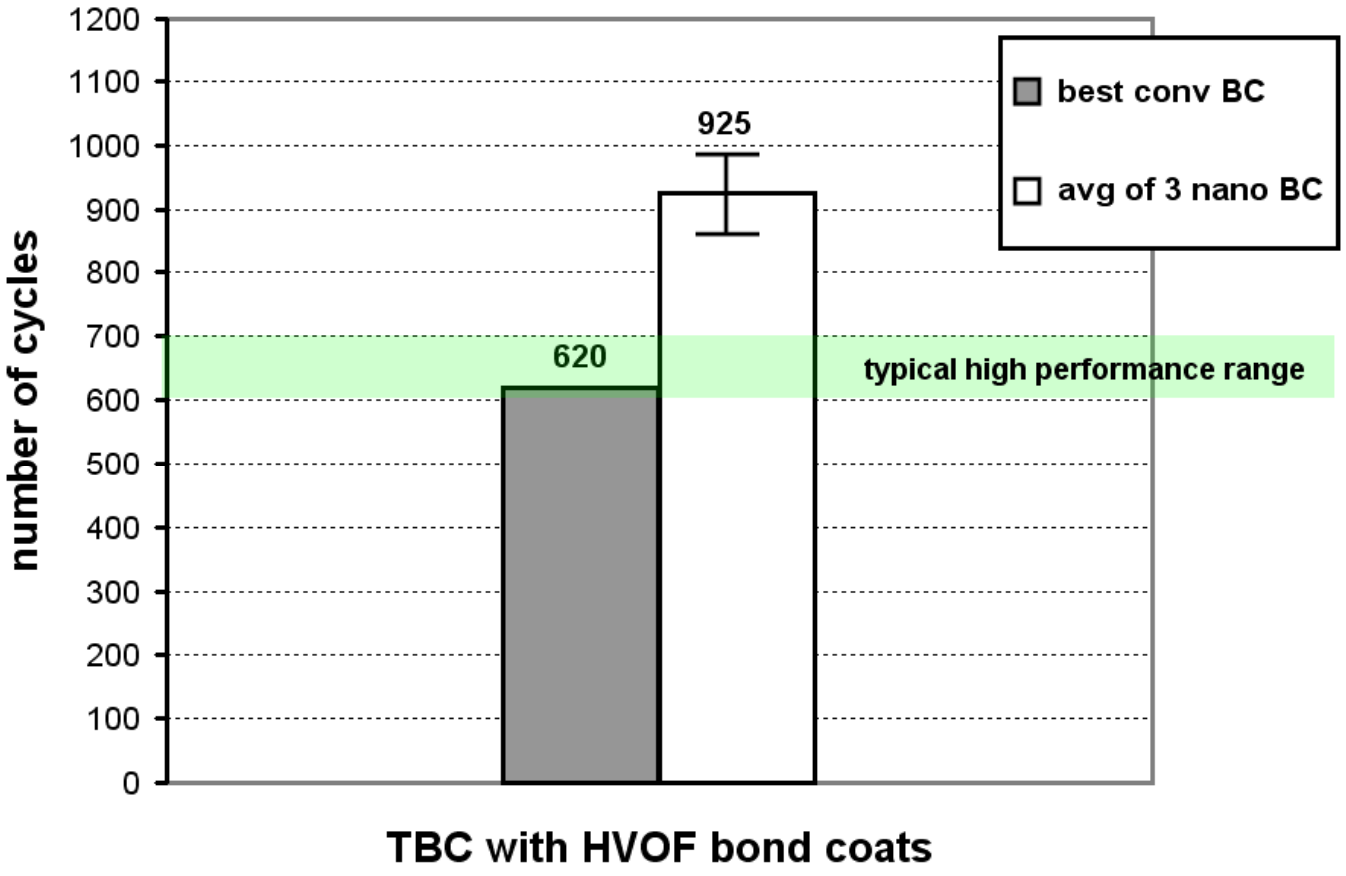
thermal cycling test



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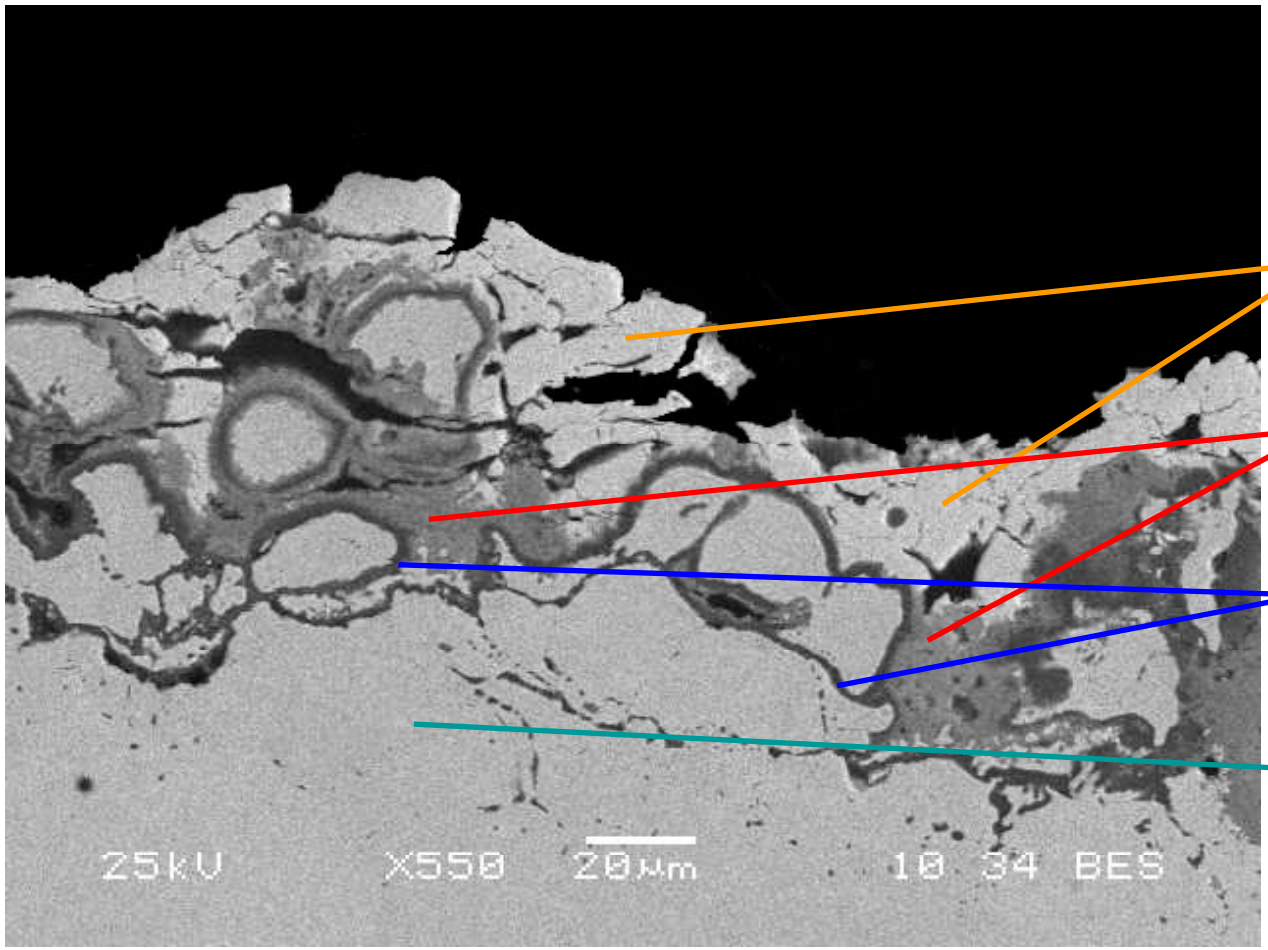
USNA

TBC with conventional bond coat



PSZ top coat

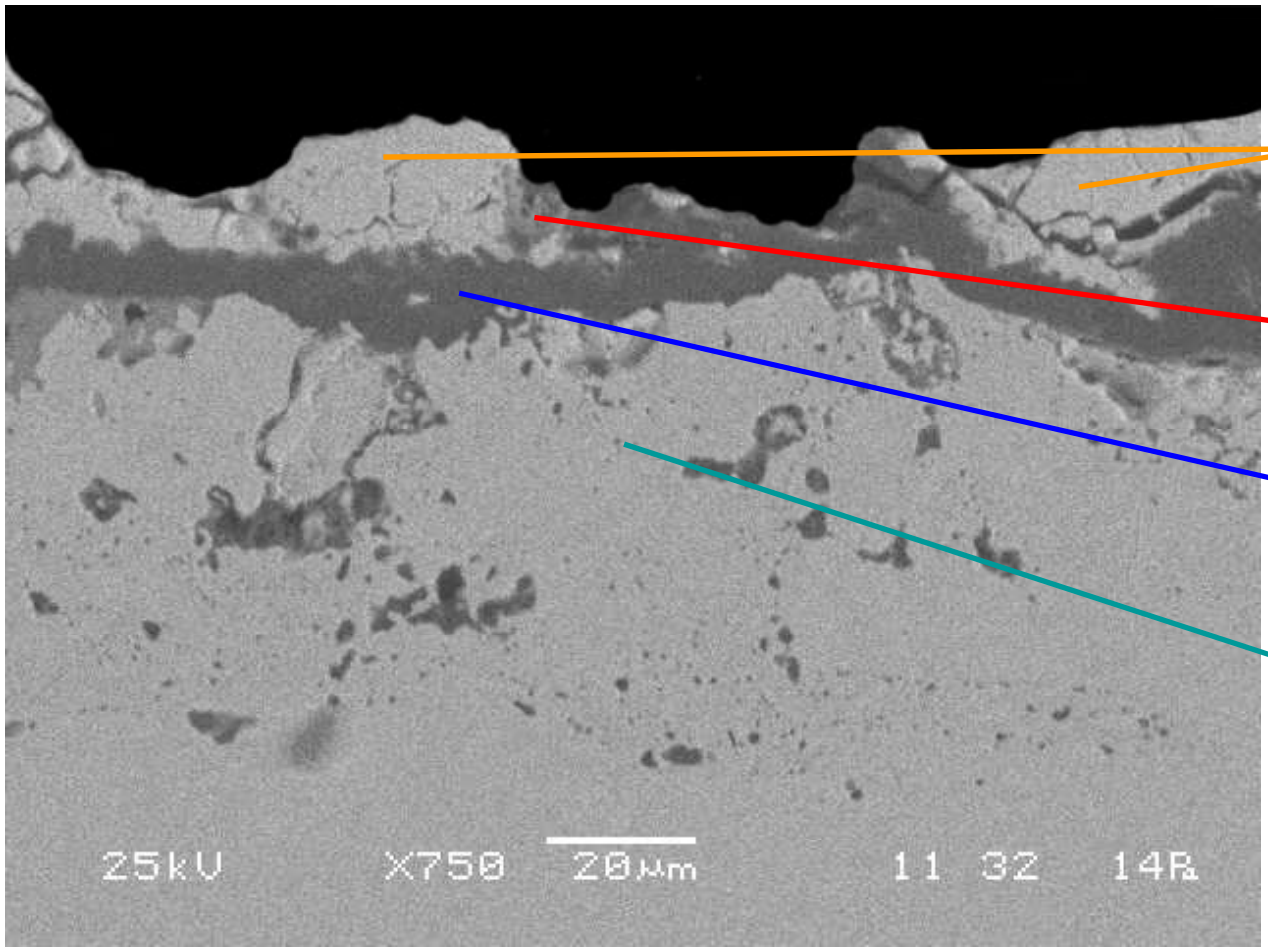
mixed oxide TGO

alumina TGO

bond coat

USNA

TBC with nanostructured bond coat



PSZ top coat

mixed oxide TGO

alumina TGO

bond coat

USNA

feedback from USNA regarding failed TBC samples

TGO on n-NiCrAlY:

- **thicker and more continuous α-alumina layer**
- **very few and isolated regions consisting of mixed oxide**

TGO on conventional NiCrAlY:

- **duo layers consisting of alumina and mixed oxides**
- **overall thickness seemed lower (note that these samples failed 30 % sooner)**

possible mechanisms

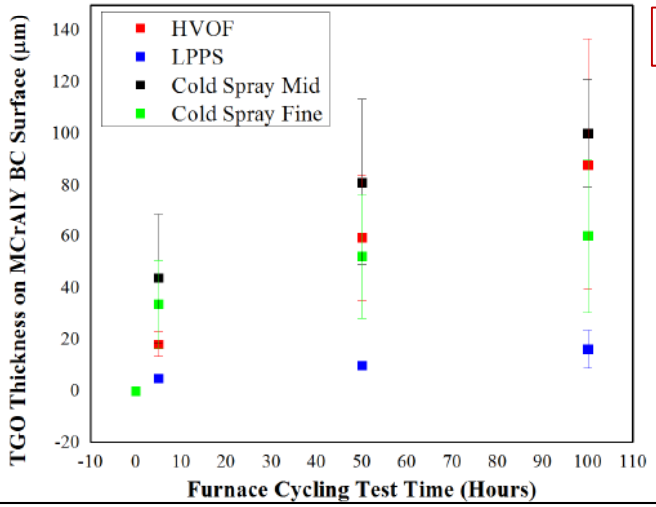
n-dispersoids…

- **may enhance alumina formation and mitigate TGO growth rate, especially the mixed oxides**
- **may contribute to a better CTE match between top and bond coats**
- **may increase bond coat creep resistance**
- **at the grain boundaries may slow down interdiffusion between bond coat and substrate**

NEEDS MUCH MORE DETAILED STUDY!!!

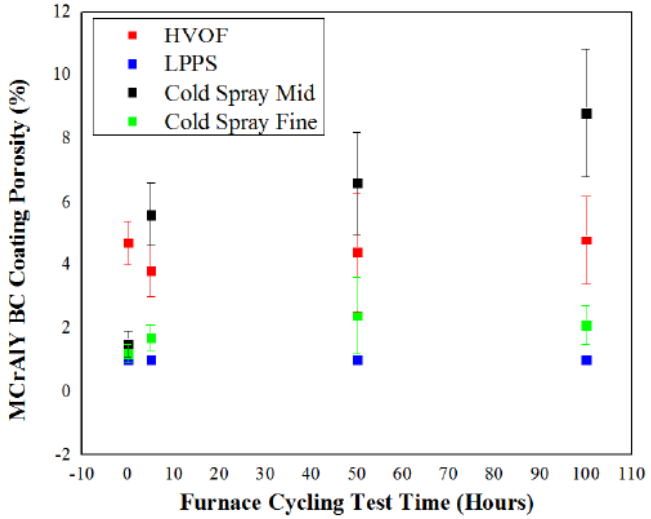
cold spray n-MCrAlY

Oxidation Behavior of MCrAlY – TGO Thickness – AS/FCT



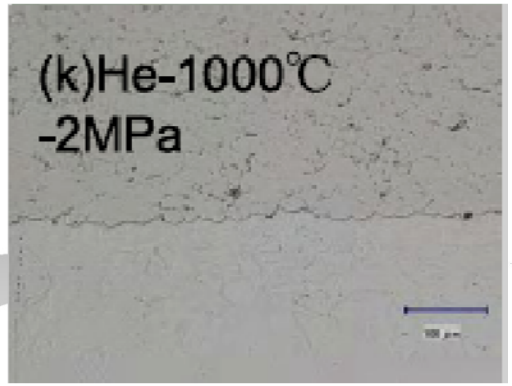
@ 1,000 ºC

Coating Porosity – AS/FCT



Barth et al. - Cold spray bond coats structure and oxidation behavior – Thermal Barrier Coatings IV (2014) – ECI

REF: Sone et al. – Comparison of CoNiCrAlY coatings…cold spray and LPPS – ITSC2012



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cold spray n-MCrAlY

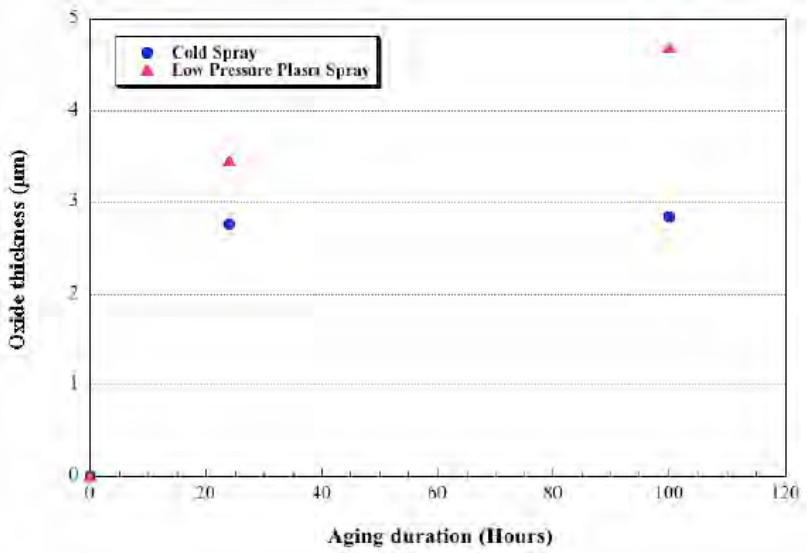

Fig. 3-15 Relationship between aluminum oxide thickness and aging duration for cold-sprayed and low-pressure plasma-sprayed CoNiCrAlY coating in 1100 °C atmospheric environment.

Table 3-2 Image analyses results of porosity measurement

Spray technique	Porosity
Cold-sprayed coating	0.363 %
Low pressure plasma sprayed coating	2.212 %

Y. Ichikawa - Elucidation of Deposition Mechanisms of Cold-Gas-Dynamic-Sprayed MCrAlY Coatings Focused on Nano-Structure – PhD dissertation – Tohoku U.

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Preliminary cold spray of n-NiCrAlY coating

(by Zhang et al. @ **State Key Laboratory for Mechanical Behavior of Materials, School of Materials Science and Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi 710049, PR China)**

- **"Nanostructured (both top and bond coats) TBCs exhibits relatively longer lifetime than the conventional coating at cycle testing at 1,150 °C."**
- **"A uniform Al2O3 layer was formed on the surface of nanostructured coating. A dual-subscale oxide formed on the conventional coating contained the inner Al2O3 oxide and an external mixed oxide composed of spinel, possibly Cr2O3 and NiO."**

Although Zhang et al.'s preliminary results look promising for cold spray n-NiCrAlY, there remains limited data in directly comparing the nanostructured coating to its conventional counterpart

cold spray n-MCrAlY

- **performance of thermal spray and cold spray MCrAlY w.r.t. oxidation seems to be related to many factors; however, between LPPS and cold spray a major factor is coating density**
- **existing literature indicate cold spray as a viable means to deposit effective MCrAlY bond coat**
- **preliminary study on cold spray nanostructured NiCrAlY yielded promising results**

SUMMARY:

- nanostructured NiCrAlY bond coats show superior resistance to oxidation and thermal cycling
- non-cryogenically milled NiCrAlY powder has been developed and shows promising results
- cold spray may provide a cost-effective means of processing optimized n-MCrAlY coatings

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acknowledgements

ACKNOWLEDGEMENTS:

- **Lawrence T. Kabacoff (ONR)**
- **Angela Moran (USNA)**
- **Warren Nelson (GE-PS)**
- **Dennis Gray (GE-GRC)**
- **Ken Scandell (NSWCCD)**
- **Julie Schoenung (UCD)**
- **Leo Ajdelsztajn (GE-GRC)**
- **Tony Addona (n-WERKZ)**
- **Mathieu Brochu (McGill U.)**
- **Victor Champagne (ARL)**
- **Aaron Nardi (UTRC)**

ATTRIBUTES OF NANOSTRUCTURED MCrAlYs

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