ENSURING DURABILITY
Testing and Evaluation for Harsh-Service Overlays
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PURCHASING VERUS VERIFYING

Specification addresses two sides of the same coin
• Detail in Purchasing assures the right product is being requested
• Detail in Verifying ensures that the purchased product is the same as was requested

Specifications form the backbone of effective product consistency and performance by ensuring that the right product is clearly defined and that both the vendor and buyer agree on the scope of supply.
PURCHASING VS VERIFYING

Two sides of the same coin

• Detail in Purchasing assures the right product is being requested
  • Specifying: The Right Product for the Application
    • What is the product need?
    • What are the acceptable limits?
    • What complicating factors exist?

• Detail in Verifying ensures that the purchased product is the same as was requested
  • Ensuring the Product Is What Was Ordered
    • Is the material right?
    • Is the location and dimension right?
    • Is the quality sufficient?
    • Is the cost and delivery as quoted?
PURCHASING VERUS VERIFYING

Is the material right?
• Chemistry
• Morphology
• Application Method

Is the location and dimension right?
• Design plan, GD&T
• Inspection Technique

Is the quality sufficient?
• Microstructure
• Nondestructive Evaluation
• Laboratory Analysis

Is the cost and delivery as quoted?
• Vendor Performance
Purchasing requirements can mandate that vendors implement and sustain a quality system such as ISO 9000, AS9100, Nadcap, etc.

Quality systems ensure:
Unique vending testing
Accuracy of testing
Repeatability of manufacturing processes
QUALITY SYSTEMS

Presence of Testing
• Does the vendor test, if so what?
• Is incoming inspection performed; outgoing?
• Will documentation be provided?

Accuracy of Testing
• Is there a calibration plan?
• Are calibrations current?
• Is the system audited by a third party?

Repeatability of Process
• Is testing performed on every order?
• Are MRB and corrective action plans in place?
• Have goals been set, met, and improved?
MEASURING THE RIGHT THINGS

HARDNESS

Macrohardness (ASTM E18)

- May be performed directly on component, no need to section, mount, polish
- Fast, test cycle is a few seconds
- Broadly available
- Suitable for nearly all thick metallic coatings

https://www.123rf.com/stocphoto/hardness.html?imgtype=0&oriSearch=indent&di=hevug8g9c58w4991
MEASURING THE RIGHT THINGS

HARDNESS

Microhardness (ASTM E384)
• Covers broadest range of hardness
• Suitable for very hard, porous, or friable materials
• Evaluates cross-sectional hardness
• Requires sectioning and polishing
• Time consuming, but can be partially automated

http://www.matstress.com/microhardness-testing.html
MEASURING THE RIGHT THINGS

Abrasion Testing (ASTM G65)

• Is overlay hardness the primary concern?
• Is lifetime wear the actual driver?
• Hard materials are often brittle and susceptible to cracking and spalling
• Composite coatings, hard particles in a softer matrix, may test lower in hardness, but provide better lifetime protection
• Not typically practical onsite

http://epimtg.blogspot.com/2012/02/
MEASURING THE RIGHT THINGS

HARDNESS

Galling, sliding, impact, etc.
- Taber Abrasion (ASTM F1978)
- Pin on Vee (ASTM D3233)
- Pin on Disk (ASTM G99)
- Block on Ring (ASTM G77)

As with G65, not usually available or practical for production testing.
MEASURING THE RIGHT THINGS

HARDNESS

Grinding

- If the overlay is to be ground
- If surface finish or diameter is critical
- If grinding parameters are well established

- Observable deviations include:
  - Chatter
  - Wheel loading
  - Excessive grind time
MEASURING THE RIGHT THINGS

ROUGHNESS

Surface conditions:
• As applied (typically >125 Ra)
• As ground (<100 Ra)
• As lapped (<4 Ra)
• Sealed

Coating material and application method will significantly impact the ability to achieve low Ra values due to microstructural conditions, especially porosity. When fine finishes are necessary, higher energy, tighter structured processes will be needed.
MEASURING THE RIGHT THINGS

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MEASURING THE RIGHT THINGS

ROUGHNESS

Creating agreement

• Stroke length and stylus
  • Surface profile is measured by tracing the height of a standard, rounded stylus as it moves across a known length of surface.
  • Stylus size and radius are standardized by manufacturer, but stroke length is often selectable between 0.01”, 0.03”, and 0.10”.

• Ra, Rz, Ry
  • Ra is the arithmetic mean of absolute probe deflection from the mean surface line.
  • Rz is the mean of the largest-peak to-mean and valley-to-mean measurements in each of 5 measurement segments within the overall sample length.
  • Ry is the maximum peak to valley difference.

Where agreement between purchaser and vendor are critical, both should use the same gauge make and model and stroke length.

From “Quick Guide to Surface Roughness Measurement” by Mitutoyo
MEASURING THE RIGHT THINGS

ROUGHNESS

Optical and laser profilometry
• Eliminates stylus radius
• Speeds sampling, fewer errors
• Higher hardware cost, for now

Bubble testing, hi-spot blue, tape test
• Nondestructive, inexpensive
• Evaluates surface finish under usage conditions

https://www.zygo.com/?/met/profilers/zegage/
https://jintest.com/control-valve-leak-rate-tester/
MEASURING THE RIGHT THINGS

MICROSTRUCTURE

Microstructural observations
• Cracking
• Delamination
• Interface Contamination
• Porosity
• Oxide Inclusion
• Unmelts
MEASURING THE RIGHT THING S

MICROSTRUCTURE

Visual references, subjectivity
MICROSTRUCTURE

Image analysis, subjectivity
MEASURING THE RIGHT THINGS

MICROSTRUCTURE

Image analysis, subjectivity

6.36%
MEASURING THE RIGHT THINGS

MICROSTRUCTURE

Mercury intrusion porosimetry
- More accurate than optical methods
- Pore volume, aperture size, and size distribution data
- Limited availability

CT scan
- Pore volume and distribution data
- Not widely available
- Highly accurate
- Looks neat
- Expensive

https://www.youtube.com/watch?v=o2SngGtG6Mc
MEASURING THE RIGHT THINGS

ADHESION

Tensile Testing (ASTM C633)
• Broadly adopted
• Widely available
• Reliably gauges coating cohesion and adhesion
• Quantifiable and simple to assess

Image courtesy Hayden Corporation all rights reserved
http://www.watsongrinding.com/products-services/metallurgical-lab/
MEASURING THE RIGHT THING S

ADHESION

Tensile Testing (ASTM C 633)
• Sensitive to:
  • Specimen alignment
  • Adhesive curing
  • Handling and preparation
→ 3/5 Samples, remove outliers
3M EC-2086, aerospace structural adhesive, shear to 5,000 psi
Cytec FM 1000, aerospace structural adhesive sheet, shear to 7,000 psi
3M Scotch-Weld 2214, aluminum filled epoxy, UTS=10,000 psi

Image courtesy Hayden Corporation all rights reserved
http://www.watsongrinding.com/products-services/metallurgical-lab/
MEASURING THE RIGHT THINGS

ADHESION

Bend Testing (ASTM D522)

• Fast
• Field portable
• Worst case scenario
• More similar to application
• Must be tailored to coating (thickness)

FIGURE 1. Coupon bend test, accept or reject examples.

MIL-STD-1687A

http://www.senze-instruments.com/mandrel-bend-tests.html
SuUiability/applicability
Thermal Spray
• Most coatings are intended to operate in compression
• HVOF coatings will tend to fail above adhesive limit (go-no-go)
• Testing error may exceed utility, false positive
• Sustains old perceptions of failure proclivity
• Spraying methodology must be the same, part to slug

Cladding/Hardfacing
• Standard methods are not well established
• Cracking may be acceptable in service, but fail in evaluation
• Sample and loading geometry should be similar to part
• Conventional mated-pair test will not achieve correct load

https://www.youtube.com/watch?v=5c-ZkUeIY5g
ICP, XRF, Spark OES
• Fast, reliable results for most metals, some units field portable (XRF)
• Easy to use, software enabled, with libraries
• Verifiable with known references
• Limited to heavy elements; no carbon, oxygen, or nitrogen, for instance
• Often referred to as PMI (positive material identification)

http://www.mdpi.com/1424-8220/15/5/10650
MEASURING THE RIGHT THINGS

CHEMISTRY

Carbide percentage

Composite content of overlays can be difficult to assess by spectrometry because:

• Common equipment doesn’t detect carbon
• Matrix content can obscure diffraction of tungsten

→ Alternatives:
  • Optical
  • Archimedes
Carbide percentage

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→ Alternatives:
  - Optical
  - Archimedes

\[
\rho_{\text{sample}} = x\rho_{\text{matrix}} + (1 - x)\rho_{\text{carbide}}
\]

\[
\frac{\rho_{\text{sample}} - \rho_{\text{carbide}}}{\rho_{\text{matrix}} - \rho_{\text{carbide}}} = x = \text{percent matrix}
\]

\[
\rho_{\text{sample}} = \frac{m_{\text{sample}}}{V_{\text{sample}}}
\]

\[
\rho_{\text{sample}} = \frac{m_{\text{sample}}}{(m_{\text{loaded}} - m_{\text{unloaded}})}
\]
Electrochemical Corrosion
Tafel analysis of the variable voltage / current flow data from the system can yield a useful sense of the tendency for metallic corrosion in a given electrolyte.

Experimental data can be gathered quickly from coated or uncoated samples.

Adjustments in materials selection can slow or virtually eliminate corrosion action as needed.
Magnetic permeability (ASTM A342)

Low permeability (relatively non-magnetic) materials:

Mechanical deviation of a strong magnet placed equidistant between a sample of known permeability and the test sample (method 3)

Mechanical deviation of a test sample placed within a variable and known magnetic field (method 2)

Low and moderate permeability materials:

Evaluation of inductance change in an electromagnetic system by insertion of a test sample (method 1)
MEASURING THE RIGHT THINGS

HEAT AFFECTED ZONE

- Polish, etch, measure
- Microhardness indentation
SOURCES OF VARIABILITY

**Process Variables**
- Gas pressure and flow
- Cooling
  - Gun cooling
  - Part cooling
- Energy input
  - Stoichiometry
  - Electrical power
  - Laser power
- Material feed rate

**Hardware Condition**
- Gun parts
- Powder feeder parts

**Feedstock**
- Size and skew
- Method of manufacture
- Morphology
- Agitation
Specifications and Contents
Options:

• **Define what you need**
  • Set tests and limits based on experimental or experiential data
  • Control those processes and parameters that affect part performance
  • Understand the contracted process, its limits, and what is reasonable

• **Copy from someone else**
  • Save time and overhead and thinking → reduce cost
  • Improve likelihood that all bases, or too many, are covered → increase cost
  • Limit potential vendor selection → increase cost
  • Suppliers recognize the shortcut

Ensuring quality or limiting the vendor base
VENDOR SUPERVISION

**Vendor in-house labs**
- Fast turnaround
  - Booth qualification
  - Certificates of conformance
  - Process optimization and troubleshooting

**Third party labs**
- Unbiased evaluation
- Unknown level of product familiarity
- Deciding factors
  - Sample specimen format
  - Test availability
  - Test duration
Quality Systems and Auditing

- Can mean regular product testing is in place
- Can mean gauging and systems are on regular calibration schedules
- Can mean policies are in place to address mistakes or errors
- Evidence of regular auditing can mean systems are maintained
- Systems and audits may be immaterial to actual shop practice
VENDOR SUPERVISION

Statistics and Periodicity

• Regular assessment of vendor performance can assure consistent quality
• Consistent results over a span of time is the best indicator
• Audit frequency may be reduced with statistical evidence of consistency

Testing with each shift/ each PO/ each month/ each year

Vendor QMS

• Indicates vendor compliance
• Creates a document trail
• Suggests evidence will be available for failure analysis
VENDOR SUPERVISION

Cost
- Time and materials to produce specimens
- Time and materials to evaluate
- Delay for evaluation prior to production
  - Booth idle – same cost as spraying (opportunity cost)
- Third party lab costs
- Testing cycle time (galling, corrosion)
  - Lab queue time

COST BENEFIT (RETURN)
IN CONCLUSION…

• Testing → Product Refinement
  • IF tests are appropriate to application, product goals
• Test Results → Product Definition (creates Purchaser and Vendor agreement)
  • IF test results are readily attainable
• Testing Protocols → Product Consistency
  • IF test protocols are sustained, calibrated, audited
• Testing specificity drives cost ("the difficult we do every day, the impossible takes a little longer")
• Testing intensity drives cost