ASTM G65 Wear Resistance
An Industry Benchmark

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The NanoSteel Company

Description
- Founded in 2002
- Advanced materials company focused on Redefining Steel™
- Exclusive worldwide license to US Dept of Energy’s 10 years work on nanostructured iron based materials.

Vision
- To be the worldwide leading solutions provider utilizing our patented nanostructured steel alloys for the control of Erosion, Corrosion & Wear

Expertise
- Bulk Materials Nanotechnology – Shrinking the grain / phase size of steel alloys to the nanometer length scale
- Custom Alloy Design – Rapidly designing new Super Hard Steel™ (SHS) alloys to solve customer specific issues related to Wear and Corrosion

Status
- Revolutionary SHS powders and wire in high volume production and applied using existing commercial processes
Industry Requirement of Measuring Wear Resistance

All NanoSteel Products Require ASTM G65-04
- Thermal Spray Powder and Wire
- PTA Weld Powder
- Weld Wire
- Wear Plate

Thin Coatings – Thermal Spray
- High Velocity Oxy Fuel, Wire Arc, Plasma

Buildable Coatings – Weld Overlay
- MIG, TIG, PTA Welding, Laser Cladding

Thick Coatings – Wear Plate
- Outstanding Wear Resistance in Every Pass
Major Industries Benefit by SHS Material Solutions for Wear, Erosion, and Corrosion

**Concrete & Cement**
SHS coatings inside mixer truck drums improve fuel economy, allow for increased loads and extend service life.
SHS coatings on light aluminum chutes extend service life and offer valuable ergonomic health benefits for drivers.

**Hard Chrome Alternative**
Superior corrosion resistance and equivalent abrasive wear resistance offered as alternative to hard chrome.
Iron based material chemistry of SHS has very minimal environmental impact and is highly recyclable.

**Mining & Aggregates**
67 - 73 HRc SHS weld overlay for hardfacing and wear plate for ground engaging tools and processing equipment.
Severe abrasion and impact resistance in extreme hard rock service environments.

**Offshore & Marine**
Outstanding corrosion resistance in high chlorine, salt fog, concentrated salt and seawater environments.
High resistance to severe wear from abrasion, fine particle erosion and impact.

**Power Generation**
SHS coatings extend the service life of heat exchange tubes in Biomass, trash and coal fired boilers.
Very high elevated temperature erosion resistance and excellent corrosion resistance to sulfidation attack.
Wear Resistance is Our Business

Customer Driven
- NanoSteel products are compared to Industry benchmarks
- Over 400 ASTM G65-04 measurements conducted annually since 2004 using a Falex machine

NanoSteel Goals
- Maintaining expertise toward meeting ASTM G65-04 specifications
- Provide the best reproducible honest results
- Is not in the market to manufacture or produce equipment
- Will support ASTM G65-04 procedure refinement and improvement
Our Observed Sources of Variation

- Sample Preparation
- Abrasive
- Mechanical Function
- Test Coupon Position – Gap
- Rubber Hardness
Sample Preparation

Test Specimen Preparation by Wet Processes (7.2, 7.4, 7.5)**
- Water Jet
- Surface Grind
- EDM

Dry (9.1)
- Acetone Rinse
- Furnace Dry at 120°C in Air
- Cool to Room Temperature

Weigh – 510 g / 0.0001 g Analytical Balance (6.8, 9.2, 9.8)
- Calibrated
- Exercised
- Verified with certified weight

Conclusion
- Improper drying can affect mass loss up to 0.6 g
- NanoSteel procedures mitigate the potential for mass loss error

** Numbers in ( ) refer to specific sections in ASTM G65-04
**Abrasive**

**AFS 50/70 Sand Properties (6.3)**
- **Morphology**
  - Rounded as shown in the ASTM specification
- **Size range**
  - -50 / +70 mesh verified
- **Hardness**
  - Typical of crystalline silica (quartz) 1426 – 1594 kg/mm² @ HV50
- **Moisture content**
  - 0.05% well below specified limit

**Delivery System**
- **Hopper (6.9)**
  - Only a fraction of the sand is mobile
- **Nozzle orientation and position (6.4)**
  - Sand falls over both sides of the wheel surface
- **Nozzle height relative to wheel/sample (6.4)**
  - As close as Falex system allows
- **Flow Pattern (sand curtain) (6.4.3)**
  - Smooth sheet with limited striation

**Flow Rate (6.4, 9.5)**
- **Nozzle machined**
  - Iterative process to meet required flow
- **Wide range (300 – 400 gram/minute) (6.4.3, 8.2, 9.5)**
  - Significant 0.03g mass loss variation
- **Nozzle opening maintenance**
  - Clean with wire

**Conclusion**
- Properties meet US Silica Data Sheet and ASTM G65
- Delivery System and Flow Rate can vary results by 0.03 g

**Numbers in ( ) refer to specific sections in ASTM G65-04**
Mechanical Function

Motor (6.5)**
- New bushing and spindle
  - Wheel runs true and concentric without bale arm bounce
- RPM checked with tachometer (6.5)
  - 200 RPM maintained +/- 1 RPM
- Motor translation
  - No effect on load as the sample holder fulcrum is fixed as is the center line of the wheel
- Wheel aligned flat and parallel to test specimen surface (9.8.1)
  - New time saving method developed for alignment

Applied Load (8.1)
- Force Meter measurement at various angles
- Perpendicular load is 30.9 lbs (ASTM spec 30 lb +/-3%)
- Load ¼ inch above center >30.9 lb, ¼ inch below center < 30.9 lb

Conclusion
- Bale arm “bounce” reduces mass loss – range unknown
- Mechanical action is fixed and mechanical functions are within ASTM spec

** Numbers in ( ) refer to specific sections in ASTM G65-04
Test Coupon Position in the Sample Holder

Gap Data Origin
- 1x4 inch test specimen allowed two wear scars by a 180° rotation

Position of the Test Coupon (9.3)**
- The test coupon must be inserted fully into the sample holder
- No gap between the top of the test coupon and sample holder should exist to allow sand to build up and flow over the rear of the test coupon

Conclusion
- Mass loss correction is 0.015 g – 0.045 g depending on gap height
- Test coupons must be fully inserted into the sample holder
- Backing plate must also be fully inserted into the sample holder

** Numbers in ( ) refer to specific sections in ASTM G65-04
Rubber Coated Wheel Hardness

Hardness Measurement using Durometer A Scale
- Calibrated Checkline and PTC brands
  - Increase applied pressure produces ~1 point increased hardness
- Variation on curved surface of wheel versus flat test strip
  - Measurements are operator dependent on wheel versus flat

Hardness Measurement
- Dwell Time (5 second versus zero) (6.2)**
  - 5 second consistently 2-4 points harder
- Location circumference versus side (6.2)
  - Edge most often harder than circumference
- Altitude – 4,700 foot elevation versus sea level
  - Inconclusive results
- Temperature (9.5.1)
  - Hardness decreased ~ 1 - 2 points when measured <12 minutes post test vs room temperature

Conclusion
- Measured durometer can vary between 1 - 2 points
- Durometer is operator dependent, but consistent
- Hardness consistent on circumference using 5 second ASTM specified dwell

** Numbers in ( ) refer to specific sections in ASTM G65-04
Concluded the Sources of Variation were Mitigated

- In spite of being precise in all the factors the variation in wear resistance persisted.

- Convincingly demonstrated with precise application of the ASTM G65-04 standard.

- The only factor we could not control was the rubber coated wheel.

- Conduct a Round Robin.
Round Robin – Five Independent Systems

Round Robin
- Three Falex systems
- Two home built systems
- Variety of NanoSteel products & D2 steel
- Two specific weld overlay products produced as test coupons

Observations
- Four test facilities had re-rubbered wheels from the same vendor
- One test facility used an alternate company to re-rubber wheels

Results
- Consistent results within each test facility (5.1, 11.2, 11.5)**
  - Verified with exception using varied wheels – hardness
  - Variation 0.01g mass loss with quality wheel, up to 0.03 g mass loss without quality wheel
- Inconsistent results between test facilities (11.5)
  - One test facility was consistently lower than all others and one consistently higher than all others
  - Variation 0.03 g - 0.06 g mass loss

** Numbers in ( ) refer to specific sections in ASTM G65-04
Round Robin Results

ASTM G65-04 Mass Loss
Round Robin - 3 Test Facilities
3 Weld Overlays - T15, D2, Carbide

Mass Loss (g)

Falex System | Home Built System
---|---
NanoSteel Weld Overlay | NanoSteel Weld Overlay
F1 | F2 | HB1

Carbide - 1st 6k | Carbide - 2nd 6k
Tungsten Carbide

A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | D2
Round Robin Results

ASTM G65-04 Mass Loss
Round Robin - 6 Test Facilities
3 Weld Overlays - 92, 98, LDWG

WELD OVERLAY - VENDOR
WELD OVERLAY - NANOSTEEL

Mass Loss (g)

92 98 LDWG - 1 LDWG - 2

Falex System
Home Built System

WELD OVERLAY - VENDOR
WELD OVERLAY - NANOSTEEL

F1 F2 F3
HB1 HB2 HB3
Variations in Chlorobutyl Rubber from Rubber Coated Wheel Vendor

Test facility with home built system
- Conducted comprehensive root cause analysis
- Determined the wheel rubber was the root cause
- Inconsistent rubber properties and hardness over several years
- Order multiple wheels to potentially get one good one

Test facility with Falex system
- Inconsistent rubber properties and hardness realized
- Order multiple wheels to potentially get one good one

NanoSteel with Falex system
- Conducted comprehensive root cause analysis
- Determined the wheel rubber was the root cause
- Inconsistent rubber properties and hardness over several years
- NanoSteel rubber coated wheels were consistently at 58-59 Durometer A

Conclusion – Rubber Quality
- Inconsistent batch to batch rubber from vendor
- Rubber on the wheel inhomogeneous
- Hardness varies over time
- Require rubber to meet ASTM G65-04 to provide accurate test results
- Test facility management encouraged today’s effort to obtain consistent quality rubber
Recommendations

- Consideration to the amendment of the Standard

- Using precise application of the ASTM G65-04 standard variations in wear resistance may be knowingly, but not maliciously, reported as demonstrated in the following observations.
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Problem – Variation in Wear Resistance Due to Wide Range

- Rubber Hardness
  - Range 58 – 62 Durometer A

- Sand Flow Rate
  - 300 g/min – 400 g/min

- Nozzle Location
  - Sand falling on wheel surface
  - Sand falling at interface between rubber and test coupon surface

Results
- Sand flow range permits 0.03g mass loss variation

<table>
<thead>
<tr>
<th>Sample</th>
<th>Nozzle A (306 g/min)</th>
<th>Nozzle D (388 g/min)</th>
<th>Mass Loss (g) with High Hardness ~58.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>98XX5</td>
<td>0.0833</td>
<td>0.1151</td>
<td>0.032</td>
</tr>
<tr>
<td>92XX6</td>
<td>0.0750</td>
<td>0.1049</td>
<td>0.030</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample</th>
<th>Nozzle Position Test</th>
</tr>
</thead>
</table>

- Mass Loss (g) with Low Hardness ~57

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mass Loss (g) sand falls onto wheel</th>
<th>Mass Loss (g) sand falls at rubber/test coupon intersection</th>
</tr>
</thead>
<tbody>
<tr>
<td>98XX5</td>
<td>0.0944</td>
<td>0.1311</td>
</tr>
<tr>
<td>92XX6</td>
<td>0.0781</td>
<td>0.1082</td>
</tr>
</tbody>
</table>
Conclusion

- Minimize the Range of Rubber Hardness
- Narrow the Range of Sand Flow

Result
- Obtain Consistent Results Regardless of Test Facility
Wheel Alignment to Produce Uniform Wear Scar

- Motor mount bolts slightly tightened
- Coat wheel surface that would normally contact test coupon +1/2 inch with iron powder
- Attach white paper to surface of the test coupon
- Insert the test coupon in sample holder
- Load weights onto wheel surface
- Remove weights
- Remove test coupon
- Review imprint on paper
- Adjust motor as necessary
- Repeat