



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 nano-structured 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



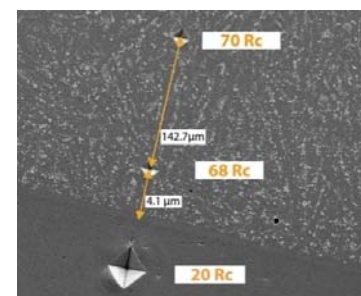
**High Velocity Oxy Fuel,
Wire Arc,
Plasma**

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



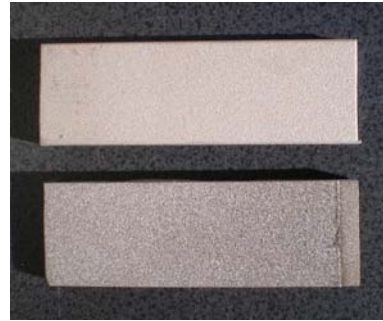
Sample Preparation

● Test Specimen Preparation by Wet Processes (7.2, 7.4, 7.5)**

- Water Jet
- Surface Grind
- EDM

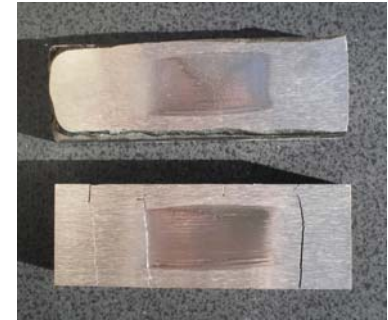
● Dry (9.1)

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



HVOF (upper) &
TWAS (lower)

Smooth Weld Overlay (upper) &
Cross Check (lower)



● 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

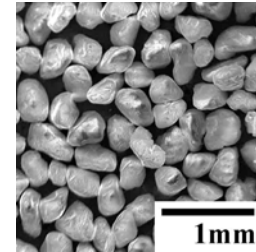
** Numbers in () refer to specific sections in ASTM G65-04



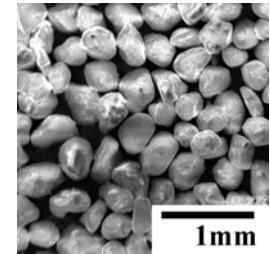
Abrasive

● 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



As Received
AFS 50/70



After G65
Procedure A

● 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



Sand Curtain

● 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

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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

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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

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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

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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

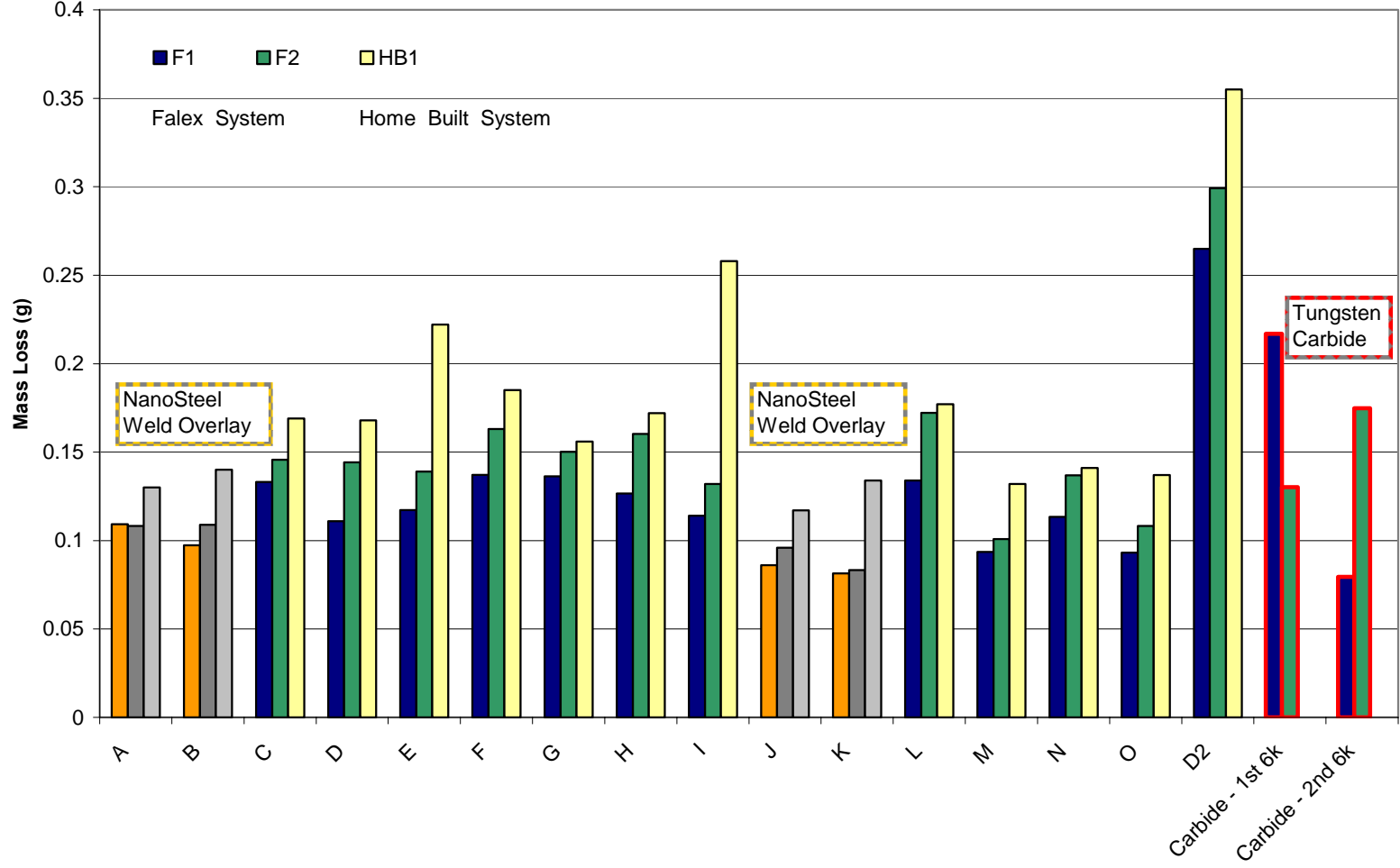
- Consistent results *within* each test facility (5.1, 11.2, 11.5)**
 - Verified with exception using varied wheels – hardness
 - Variation 0.01g mass loss with quality wheel, up to 0.03 g mass loss without quality wheel
- Inconsistent results *between* test facilities (11.5)
 - One test facility was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

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Round Robin Results

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



Round Robin Results

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



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 ammendment 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

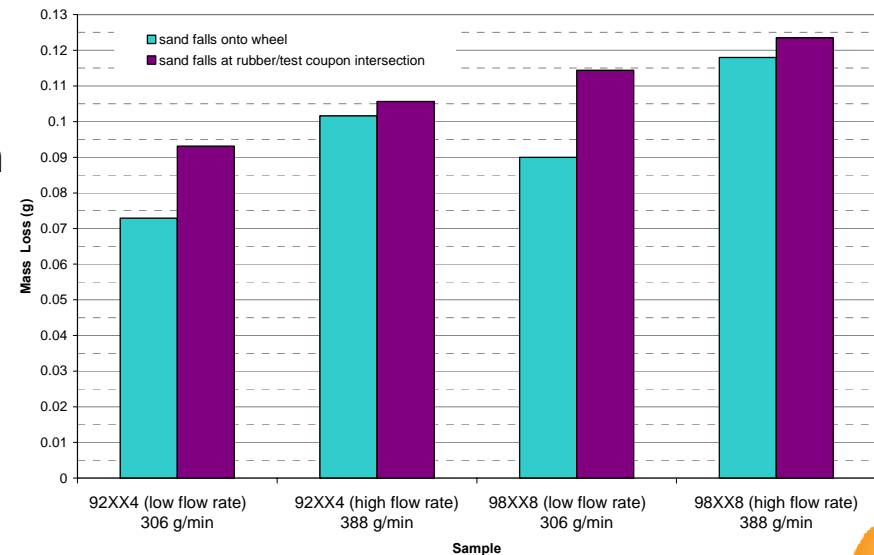
Results

- ➔ Sand flow range permits 0.03g mass loss variation

Sample	Nozzle A (306 g/min)	Nozzle D (388 g/min)	Δ Mass
Mass Loss (g) with High Hardness ~58.5			
98XX5	0.0833	0.1151	0.032
92XX6	0.0750	0.1049	0.030

Mass Loss (g) with Low Hardness ~57			
98XX5	0.0944	0.1311	0.037
92XX6	0.0781	0.1082	0.030

Sand Nozzle Position Test



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

