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Niobium-Alloyed Ferritic Nitrocarburized Brake Rotors

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CBMM
Niobium Nb

Problem Statement

- NAO copper-free friction replacements show increased rotor wear
- Low met friction materials can increase wear
- New requirements to reduce “dust emissions” for both rotor and friction materials
  - Example Euro 7
- Corrosion is a concern.
  - Electric vehicle braking, and appearance.
- Desirable alternatives need to fit into existing manufacturing foundry & supply chain.

Proposed Solution

- Niobium-alloyed ferritic nitrocarburized gray iron brake rotors can offer the desirable combination of corrosion and wear resistance.
- Supporting Research:
  - Niobium alloying provides improved wear resistance of brake rotors and drums (SAE 2020-01-1627)
  - Ferritic Nitrocarburized brake rotors improves the corrosion performance of gray iron brake rotors (SAE 2011-01-0567)
- **Proposed Solution: Combine niobium-alloyed brake rotors with ferritic nitrocarburizing (FNC)**

Production Process with Proven Technology

Manufacturing Sequence:

1. Rotors are cast in Gray Iron alloyed with Niobium. The Fe-Nb-C diagram describes the formation of Niobium carbide during cooling. Niobium carbides provide wear resistance.
2. Castings may be stress relieved to provide better dimensional control.
3. Rotors are finished machined
4. Rotors are Ferritic Nitrocarburized. The Lehrer Diagram describes the metallurgical phases. The FNC case provides corrosion resistance (and some wear resistance)
5. ***<u>No subsequent machining or grinding required.</u>***

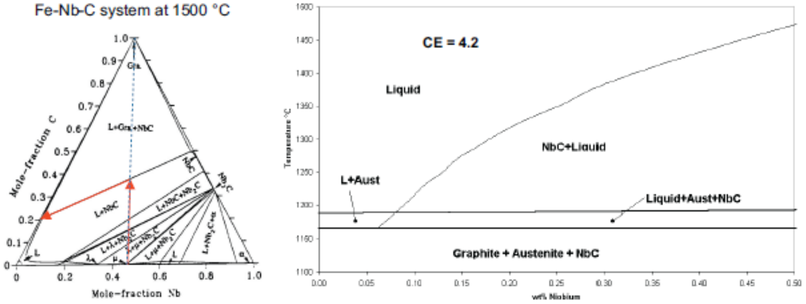
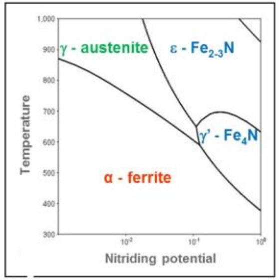
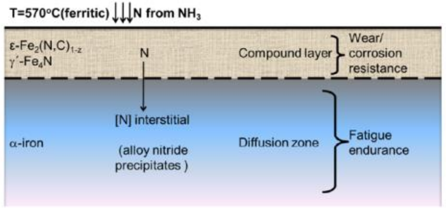


Figure 2: Phase diagrams indicating the mechanism of FeNb dissolution (left) and re-precipitation of solute Nb (right).

Lehrer Diagram

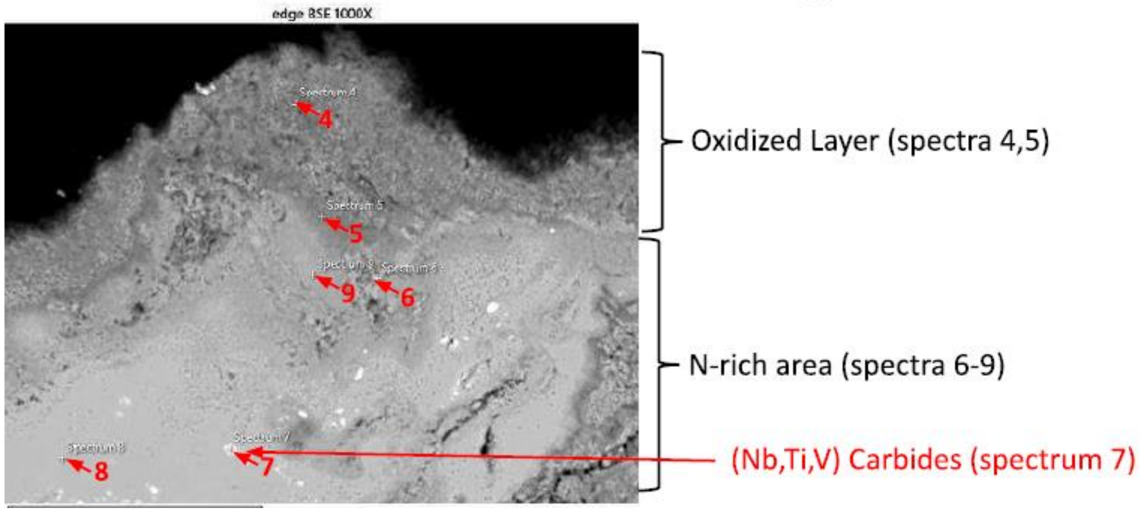


$$K_n = \frac{p_{NH_3}}{p_{H_2}^{3/2}}$$



Verification of the Effects of Niobium addition and Ferritic Nitrocarburizing

Tilted section EDS spectra on FNC edge



** Analysis verifies the presence of niobium carbides in the epsilon iron nitride ferritic nitrocarburized case

Spectrum Label	C	N	O	Si	S	Ti	V	Cr	Mn	Fe	Cu	Nb	Total
Spectrum 4	20.74		17.99	1.14	0.12			0.15	0.73	58.92	0.20		100.00
Spectrum 5	16.25		19.49	2.92	0.18			0.21	0.96	59.58	0.41		100.00
Spectrum 6	17.84	3.83	6.46	0.77	0.11				0.87	70.11			100.00
Spectrum 7	22.41	6.47		0.43		2.78	0.29	0.36	0.43	32.01		34.82	100.00
Spectrum 8	17.44	4.54		0.97				0.53	0.95	75.57			100.00
Spectrum 9	16.95	4.15	4.36	1.80					0.55	71.74	0.46		100.00

Test Matrix

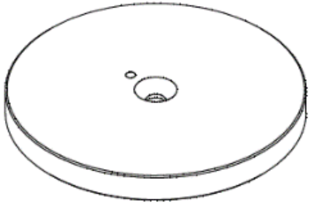
- Baseline standard high CE and eutectic gray irons
- Niobium alloyed (0.15-0.25 wt% Nb) modifications of base irons
- Ferritic nitrocarburized and as-cast samples
- NAO and low met friction materials
- 16 combinations
- 3 repetitions at each combination

Grades		G135 High CE Baseline	G205 Baseline	G135Nb	G205Nb
		Mechanical Properties			
Ultimate Tensile Strength, Minimum	N/mm^2	135	205	180	235
Hardness	HBW	156 to 207	187 to 229	170 to 221	197 to 235
		Chemistry			
Carbon Equivalent	% by mass	4.30 to 4.60	3.90 to 4.30	4.30 to 4.60	3.90 to 4.30
Carbon		3.65 to 3.95	3.20 to 3.50	3.65 to 3.95	3.20 to 3.50
Silicon		1.75 to 1.95	1.90 to2.40	1.75 to 1.95	1.90 to2.40
Manganese		0.50 to 0.80	0.45 to 0.90	0.50 to 0.80	0.45 to 0.90
Sulfur		0.12 max	0.12 max	0.12 max	0.12 max
Phosphorus		0.10 max	0.10 max	0.10 max	0.10 max
Chromium		0.25 max	0.15-0.40	0.15 to 0.40	0.15 to 0.40
Copper		0.40 max	0.60 max	0.40 max	0.60 max
Tin		0.07 max	0.07 max	0.07 max	0.07 max
Niobium		0.10 max	0.10 max	0.15 to 0.25	0.15 to 0.25
		Microstructure			
Brake Surface		70% Type A, Size 3 to 8 in a Pearlitic Matrix with <10% free ferrite and < 1% carbides	70% Type A, Size 4 to 8 in a Pearlitic Matrix with <10% free ferrite and < 1% carbides	70% Type A, Size 3 to 8 in a Pearlitic Matrix with <10% free ferrite and < 1% carbides	70% Type A, Size 4 to 8 in a Pearlitic Matrix with <10% free ferrite and < 1% carbides
Number of Bruker Test Samples (3 non FNC, 3 FNC)		6	6	6	6
Brake Rotor Castings		6	6	15	12

Test Procedures

- UMT Bruker TriboLab Tester Testing (GTL 22584)
  - Laboratory test on cast disc samples
- SAE J2707 Wear Test Procedure Method B Block Wear (Currently on test on solid brake rotor)
- Inertia Dynamometer Cyclical Rotor Corrosion Cleanability for FNC Rotor Applications (Currently on test on solid brake rotor)

Bruker Sample
Cast Disc

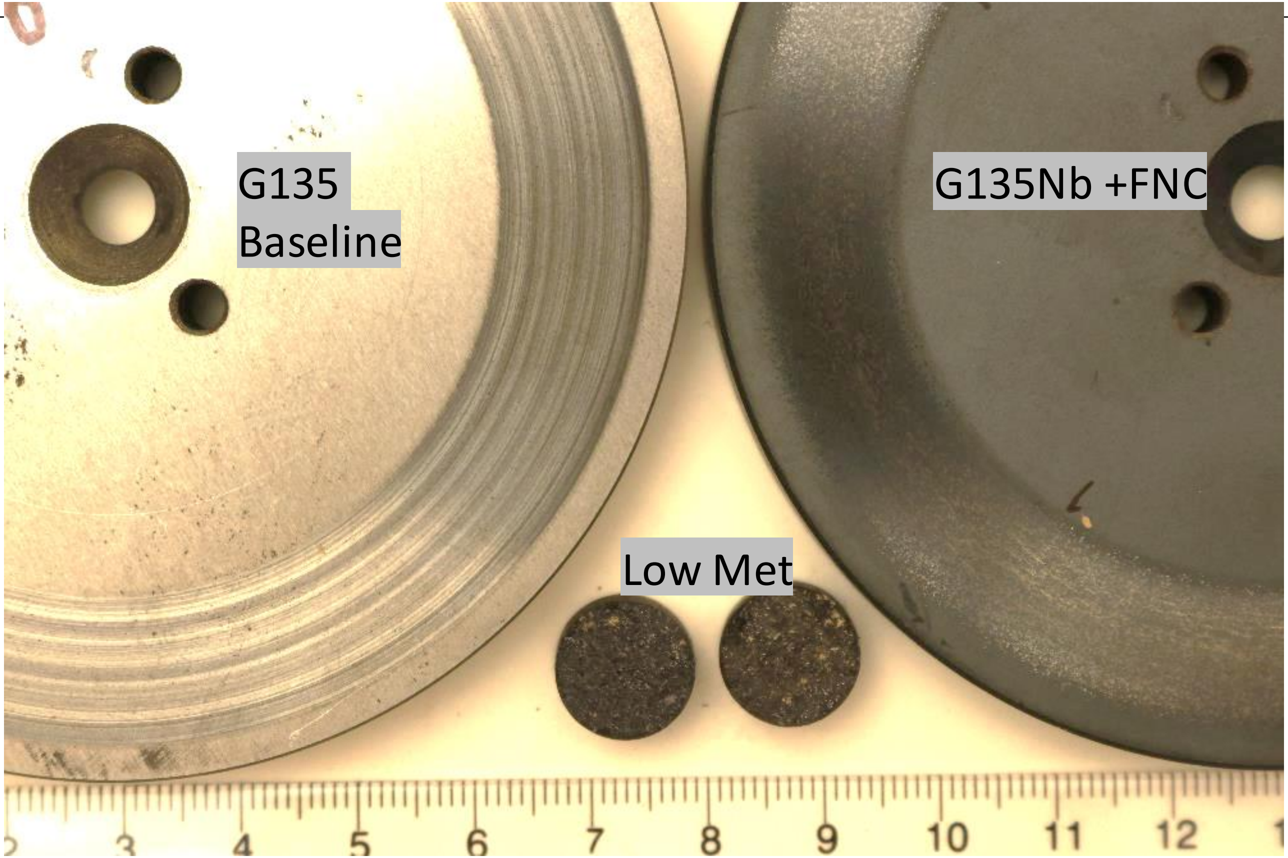


Dynamometer Sample
Cast Brake Rotor

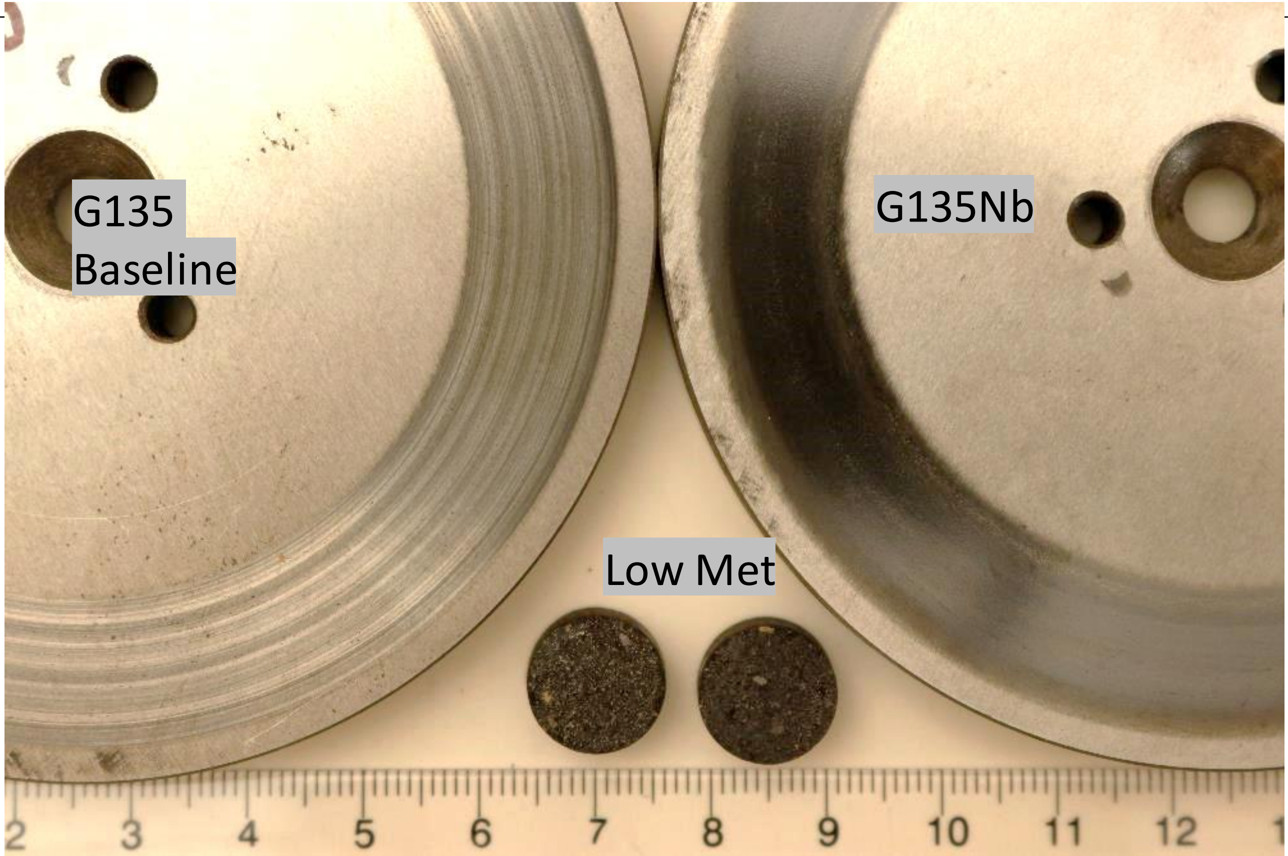
Greening Test Lab (GTL)Test Protocol

- Burnishing procedure to obtain 90-95% of the friction contact area.
- GTL speed sensitivity snub test procedure, Bruker Tribolab HD
  - Repetition of the 20 snubs on the following test speed interval sequences: 40-0.5, 60-20, 80-40, 100-60 and 120-80 km/h.
  - Each test sequence was performed at one unit load value.
  - 0.5, 1.0 and 1.5 MPa.
  - Between starting each test mode, the parts were allowed to cool.

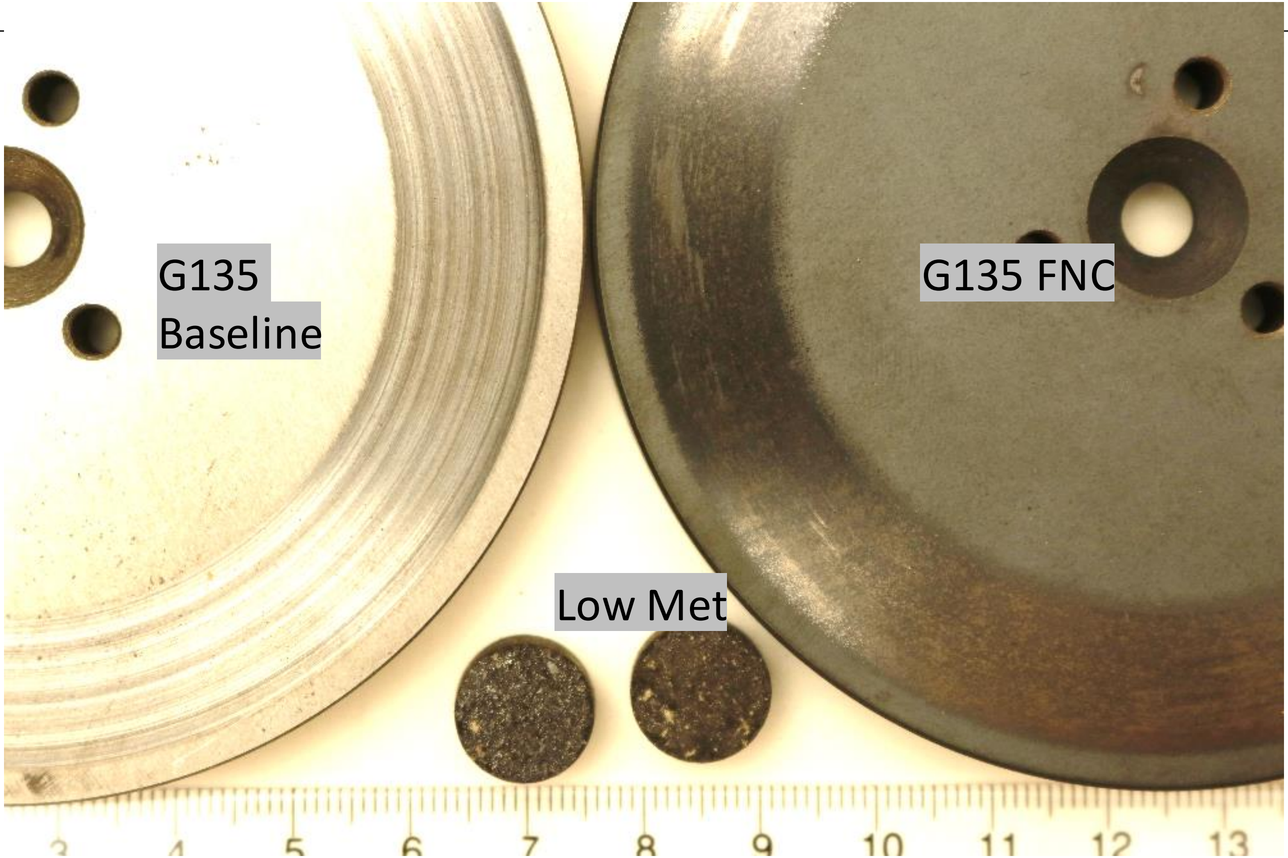
Significant reduction in wear compared to baseline



Significant reduction in wear compared to baseline

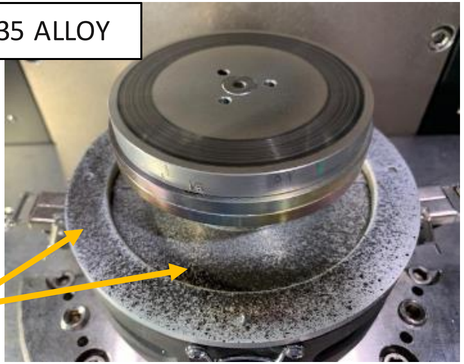


Significant reduction in wear compared to baseline



High Carbon Equivalent Gray Iron, Low Met Friction

G135 ALLOY



Brake Dust

Less Brake Dust

G135 ALLOY with NIOBIUM

G135 ALLOY with NIOBIUM and FNC

MUCH Less Brake Dust

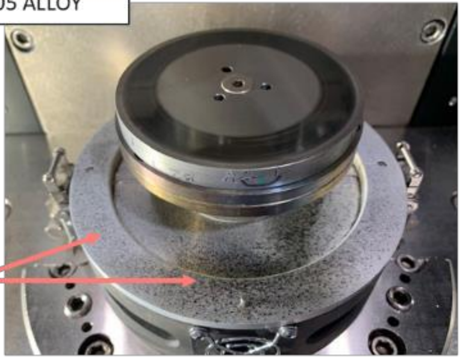
BACKGROUND:

- Bruker wear test at Greening, Inc in Detroit MI
- Low met friction material
- Niobium 0.15 – 0.25wt%

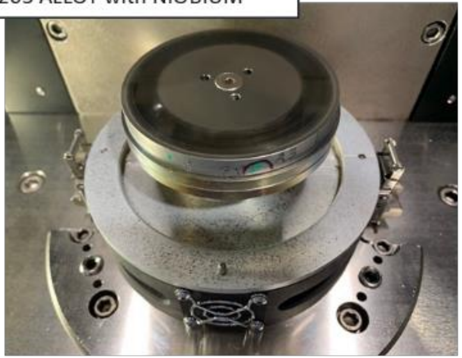
Standard Eutectic Gray Iron, Low Met Friction

G205 ALLOY

Brake Dust

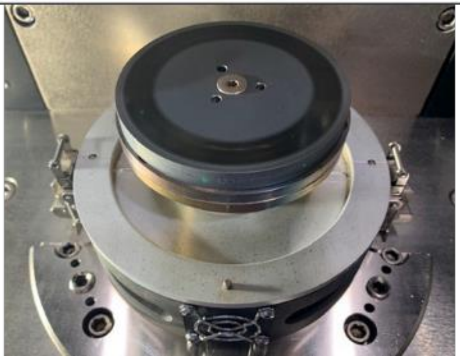


G205 ALLOY with NIOBIUM



Less Brake Dust

G205 ALLOY with NIOBIUM and FNC



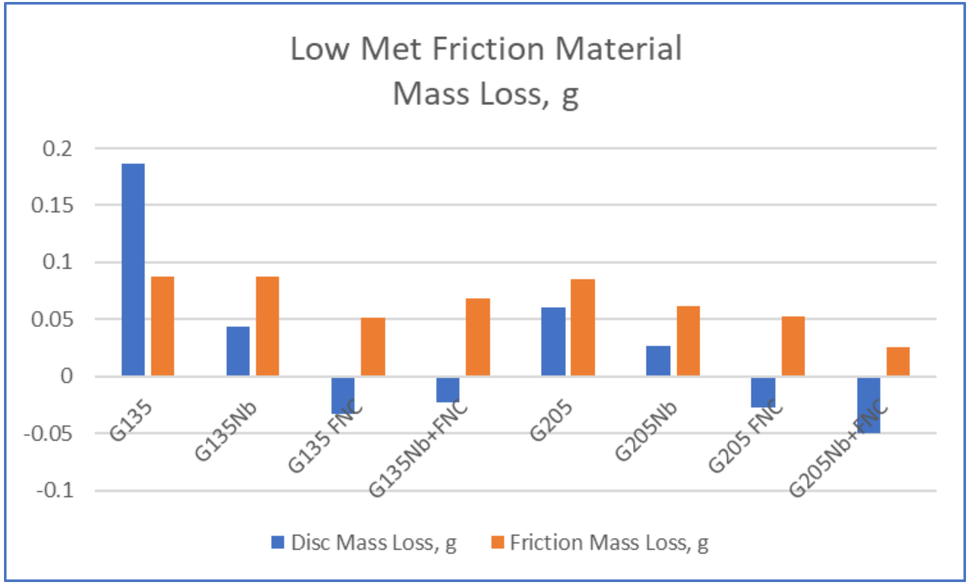
MUCH Less Brake Dust

BACKGROUND:

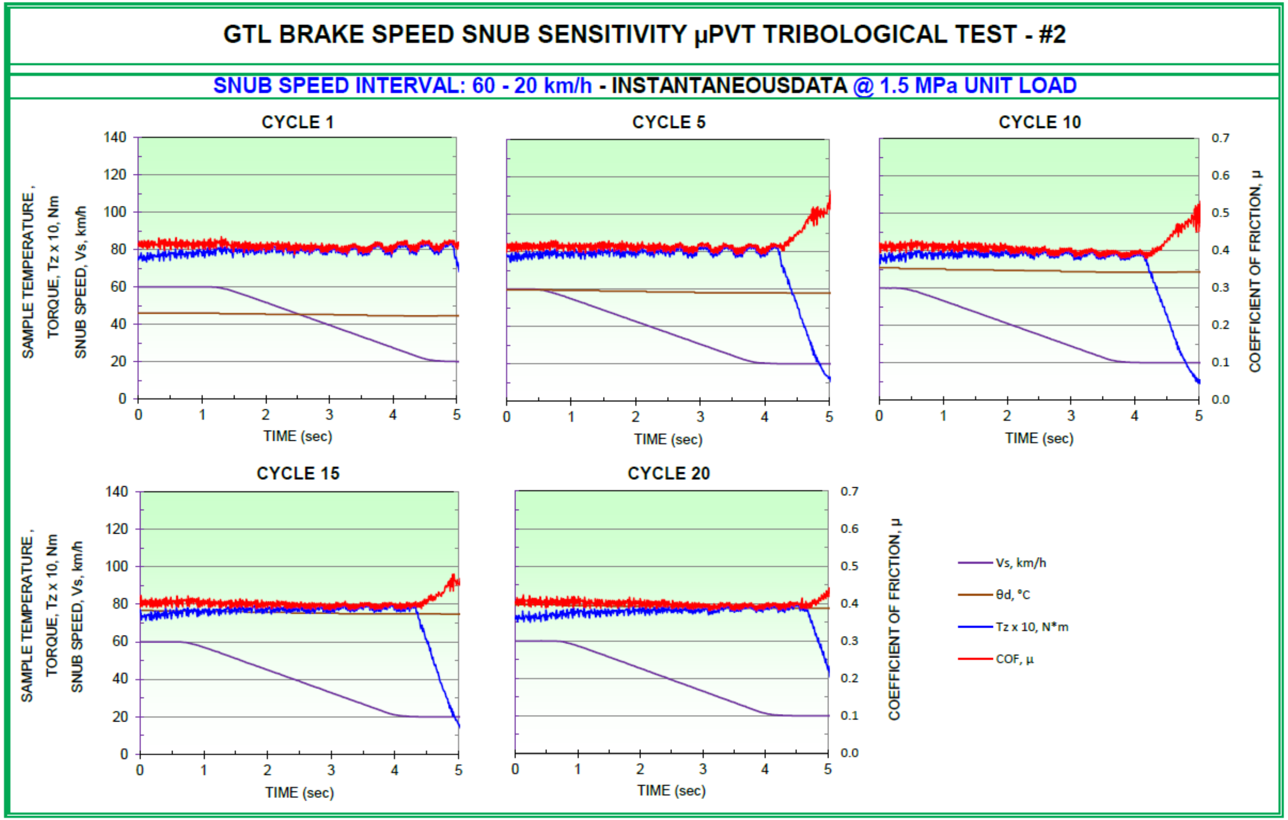
- Bruker wear test at Greening, Inc in Detroit MI
- Low met friction material
- Niobium 0.15 – 0.25wt%

Test Results

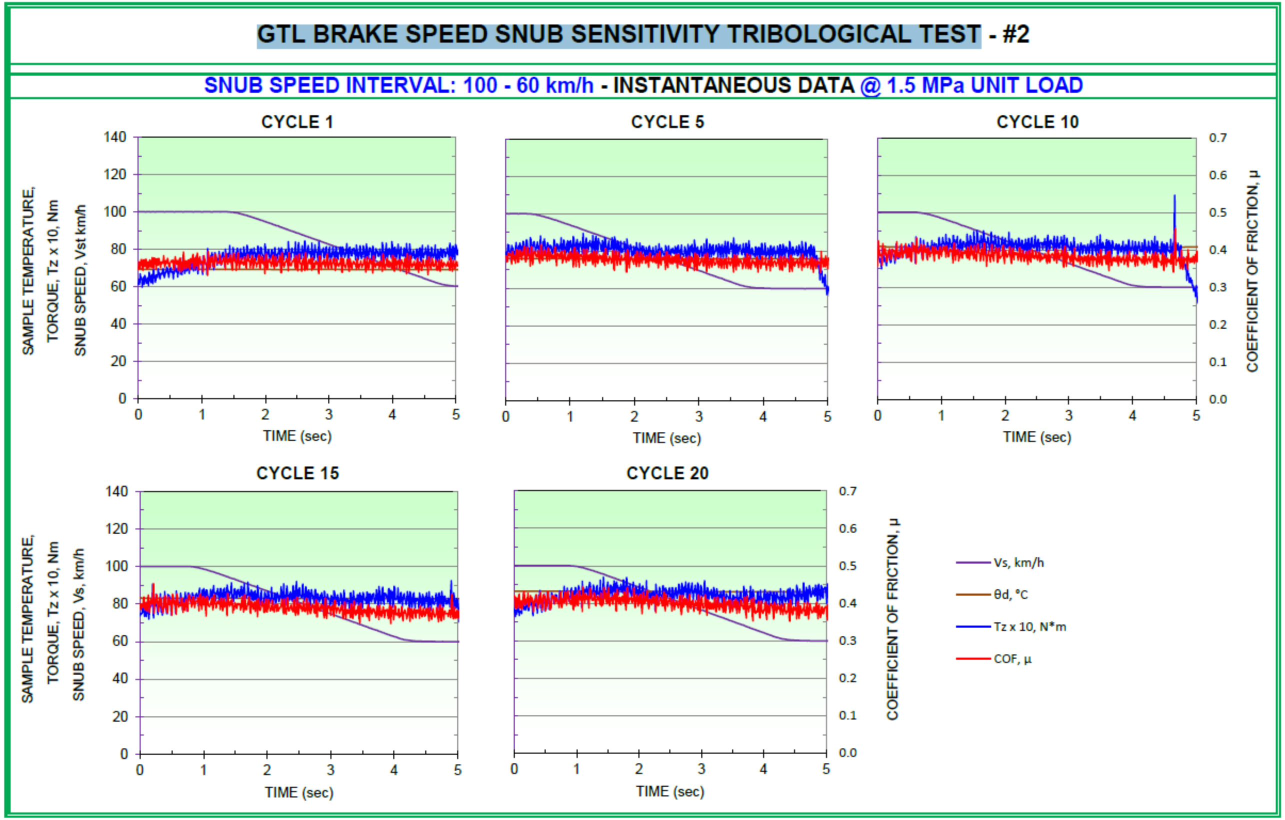
Niobium-alloyed ferritic nitrocarburized samples show the best combination of wear resistance



GTL BRAKE SPEED SNUB SENSITIVITY TRIBOLOGICAL TEST-G135 Baseline Low Met Friction



GTL BRAKE SPEED SNUB SENSITIVITY TRIBOLOGICAL TEST-G135Nb+FNC Low Met Friction



Brake Rotor Corrosion Cleanability - End of Test

G135 ALLOY

Corrosion
Scale on Brake Surface

G135 Plus FNC

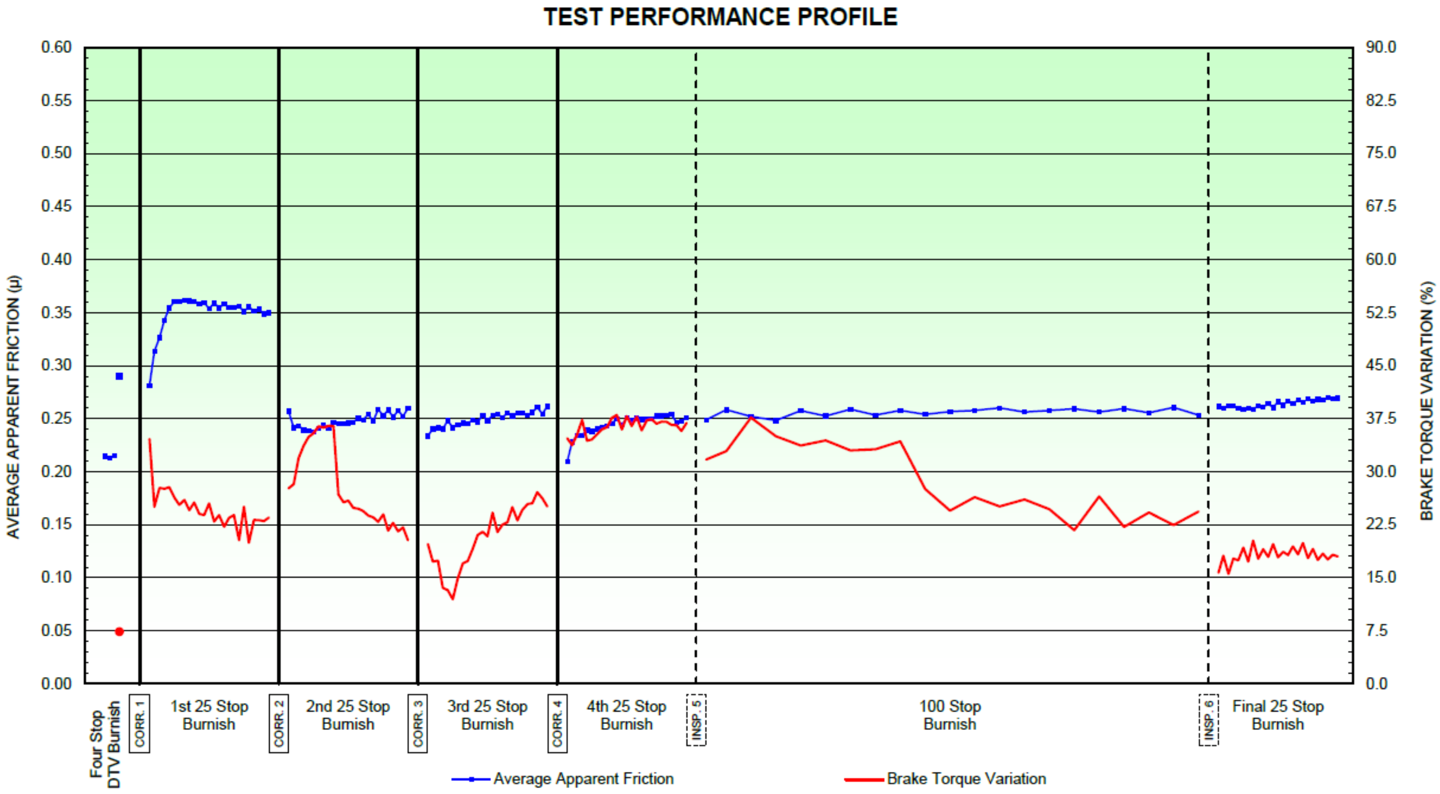
Reduced Corrosion Scale,
Improved Cleanability

G135 ALLOY with NIOBIUM and FNC

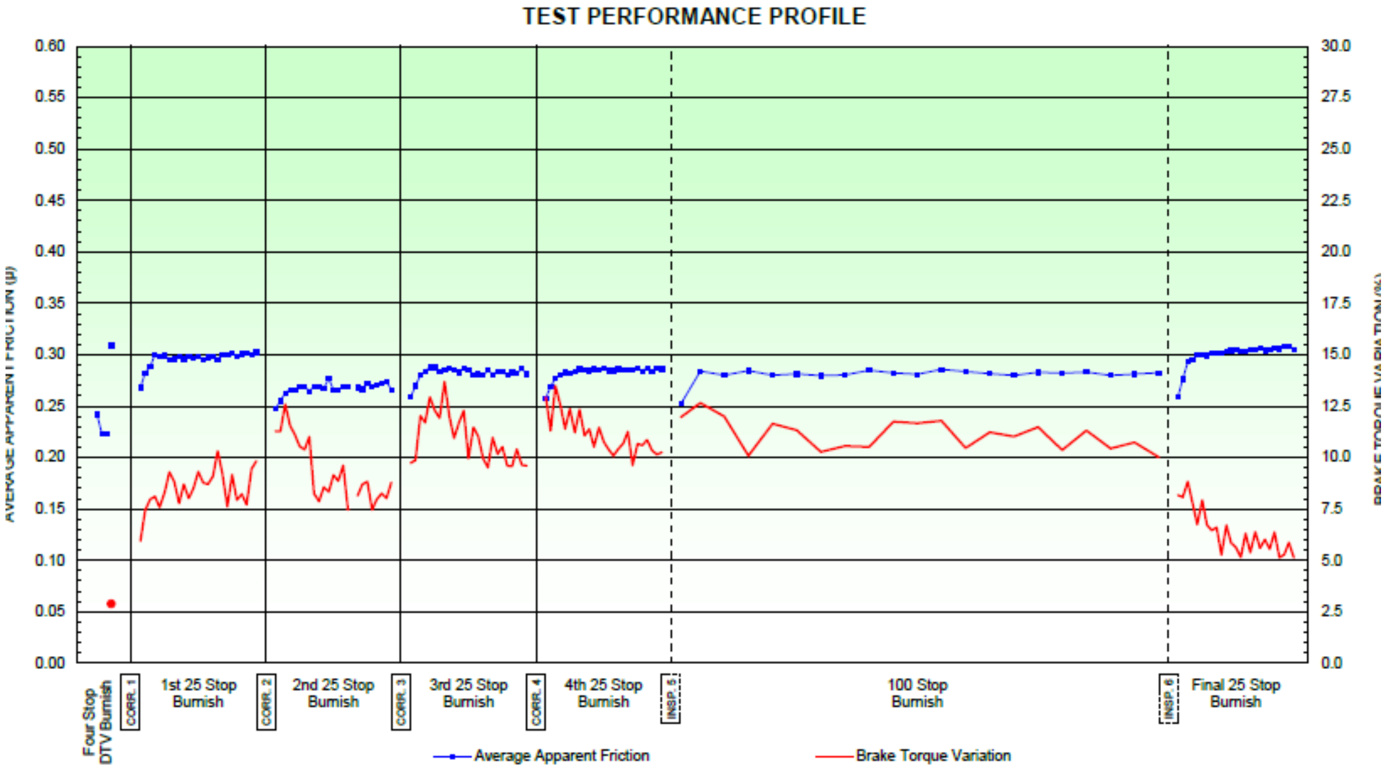
Superior Cleanability
and Improved Wear

BACKGROUND:
- Corrosion Cleanability
- NAO friction material
- Niobium 0.15 – 0.25wt%

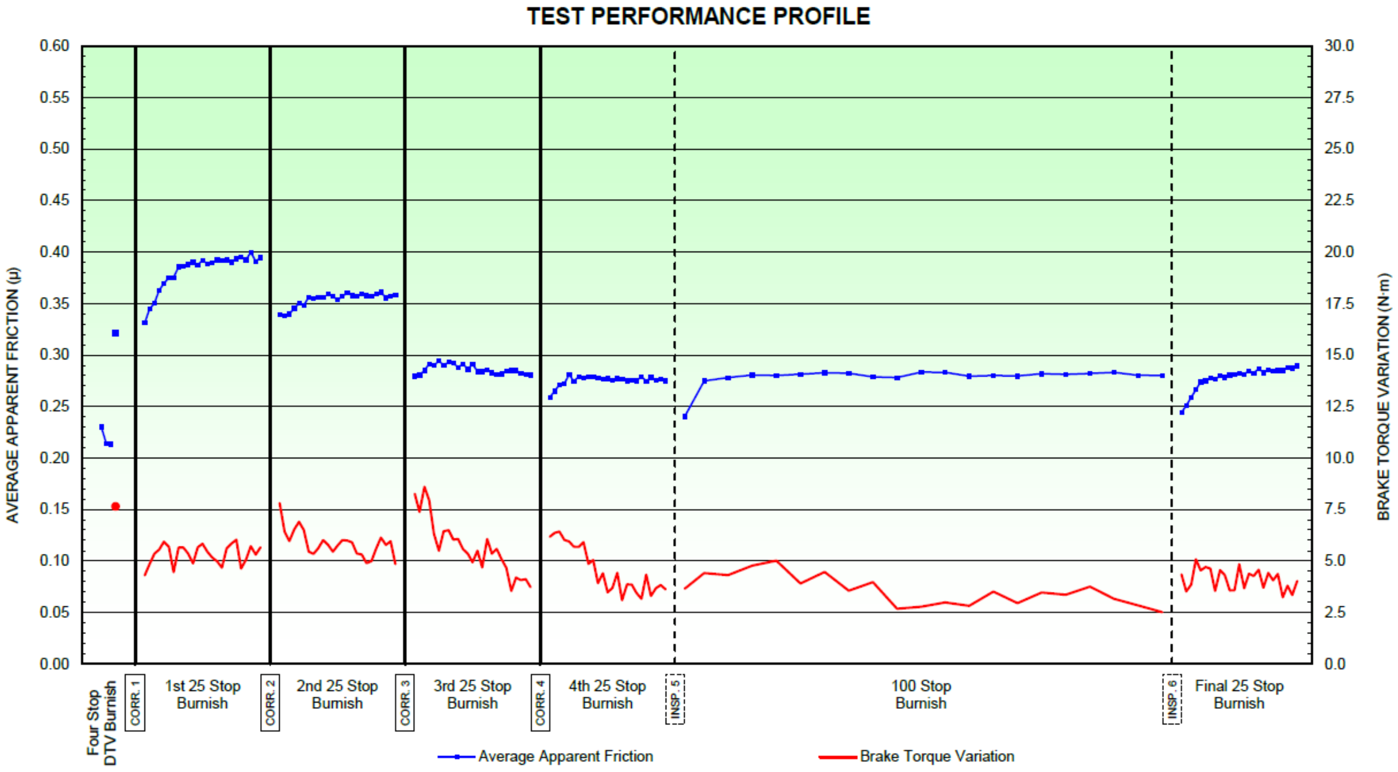
Corrosion Cleanability-Apparent Friction and Brake Torque Variation-G135



Corrosion Cleanability-Apparent Friction and Brake Torque Variation-G135 FNC



Corrosion Cleanability-Apparent Friction and Brake Torque Variation-G135 Nb Plus FNC



Comparison to Competitive Technology

Technology	Wear Resistance	Corrosion Resistance	Potential for debond and peeling	Thermal Expansion Missmatch	Requires Post Grinding	Environmental	Cost
G135 Baseline	Low	Low	None	None	No	Baseline	Baseline
G135 Nb + FNC	++	++	None	None	No	+	-
Laser Hard Surfacing	++	++	High	High (Austenitics)	Yes	--- (Grinding swarf)	--- (5x higher than FNC)

Niobium-alloying with FNC offers the following advantages over laser hard surfacing:

- Ferritic nitrocarburizing and niobium alloying are “in the metal.”
- Same foundry processing & machining.
- No change, or minimal change required for friction materials.
- No post-grinding
- No grinding swarf to reclaim and waste treat
- Significantly lower cost than hard coat surfacing.
- Laser hard surfacing is a coating that must form a metallurgical bond with the surface that can show a debond failure mechanism.

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