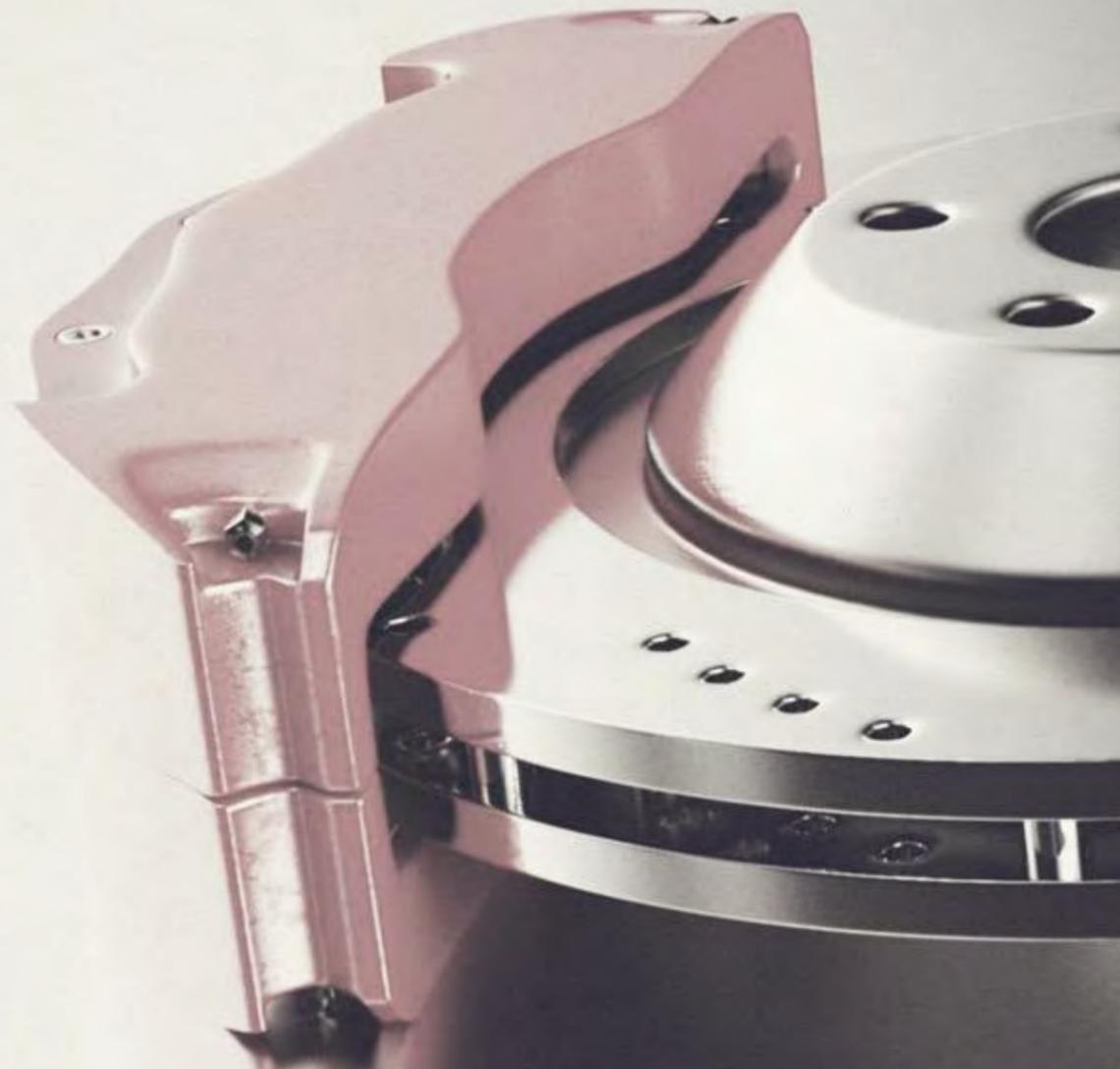


 **CBMM** | Niobium N5

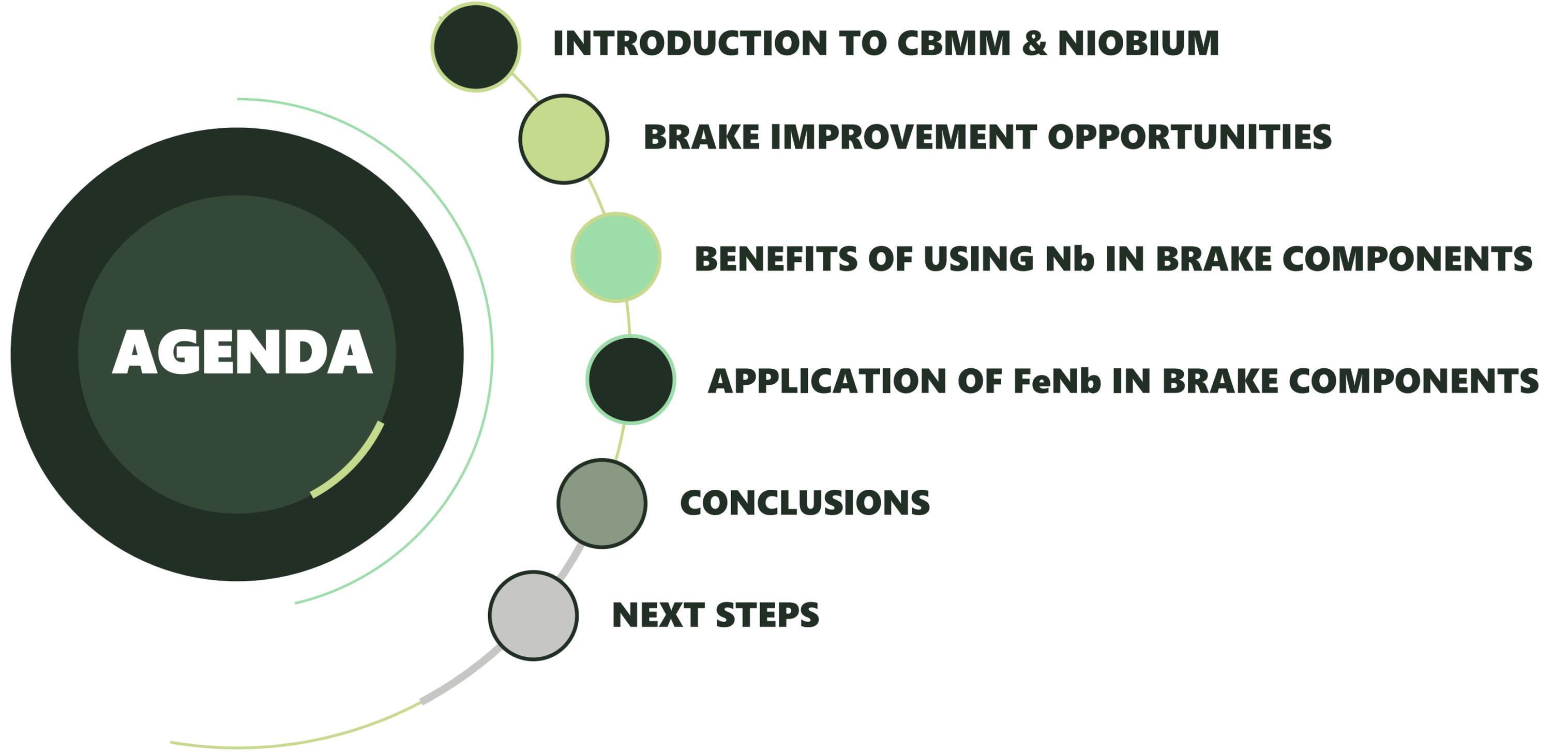
# **INTRODUCTION TO NIOBIUM BRAKES**

**JULY 2020**



**BRAKES CLEARLY PLAY A VITAL ROLE IN PROVIDING A SAFE DRIVING EXPERIENCE AND PERFORMANCE DEMANDS HAVE INCREASED AS THE PERFORMANCE OF VEHICLES HAS INCREASED ALSO**

**NIOBIUM MATERIALS TECHNOLOGY, WHEN APPLIED TO BRAKE COMPONENTS, ALLOW FOR MORE RELIABLE, HARDER-WEARING AND BETTER DESIGNED BRAKES TO BE PRODUCED AND FITTED TO ANY VEHICLES**





# ABOUT CBMM & NIOBIUM

Introduction to Niobium Brakes



**CBMM  
A GLOBAL  
MATERIALS  
TECHNOLOGY  
LEADER**



**MATERIALS  
TECHNOLOGY  
INNOVATOR**

**WORLD'S  
LEADING  
SUPPLIER OF  
NIOBIUM**

**1,950  
PROFESSIONALS  
& 500  
CUSTOMERS**

**GLOBAL  
SUPPLIER  
TO THE  
AUTOMOTIVE  
SECTOR**

**BASED IN  
BRAZIL WITH  
GLOBAL  
OPERATIONS  
& PARTNERS**

**FORMULA E  
PARTNER  
2017-21**

**EXTREME E  
LAUNCH  
PARTNER AND  
SUPPLIER**



# CBMM WORLDWIDE:

**CBMM IS ABLE TO SUPPORT CLIENTS NEEDS QUICKLY AND EFFICIENTLY. Nb TECHNOLOGY CAN DELIVER SMART SOLUTIONS FOR BUSINESS.**



- HEAD OFFICE
- PUBLIC RELATIONS OFFICE
- MINE / INDUSTRIAL FACILITY
- SUBSIDIARIES
- CBMM SWISS TECHNOLOGY OFFICE
- EXCLUSIVE DISTRIBUTORS

CBMM IS CERTIFIED: iso 9001 – 17025 – 14001 e NADCAP

# MICROALLOYING CONCEPT



**BODY**



**WHEELS**



**CHASSIS**



**TRANSMISSION**



**POWERTRAIN**



**NANO & ELECTRONICS**



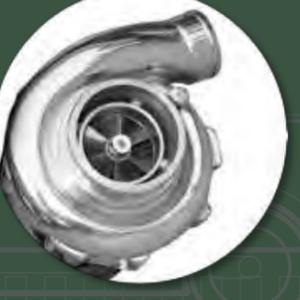
**LIGHTWEIGHTING**



**BRAKES**



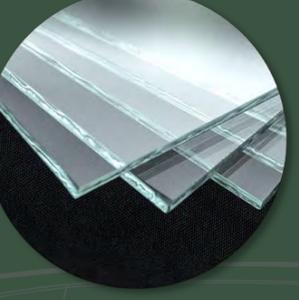
**EXHAUSTS**



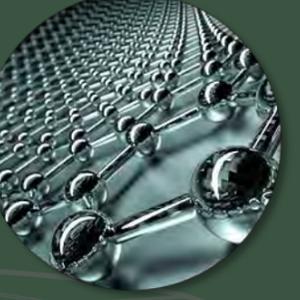
**TURBOCHARGERS**



**BATTERIES**



**GLASS**



**NEW R&D MATERIALS**

## **NIONIUM**

COMMERCIAL VEHICLES, PASSENGER VEHICLES, HIGH PERFORMANCE, FUTURE OF MOBILITY



# CBMM NIOBIUM ADDING VALUE: STRONGER, LIGHTER, SMARTER, SAFER VEHICLES

## Stronger Structures

- Lighter – between 10% and 20% for some parts
- Stronger and tougher
- Up to 15% reduction in steel volumes
- Benefits for steel and aluminium parts
- More efficient production processes

## Smart Windows

- Controlling visible sunlight
- Managing Solar heat
- Improving driver/passenger experience
- Enabling fuel savings
- Reduces CO2 emissions

## Efficient E Engines

- Niobium in Nanocrystalline
- More efficient process of converting electrical energy from the battery into motion
- Important in electric motors
- Also improving inverters

## Advanced Engines & Turbochargers

- Lighter, stronger engine blocks, and cylinder heads
- Better performing Turbochargers
- Parts more resistant to wear
- Reduced failure rate
- Niobium allows more complex and innovative designs

## Safer Batteries

- Increase battery performance
- Improving service life
- Safer Batteries
- Increasing stored energy
- Faster charging times
- Prevent short circuits

## Resilient Electronics

- Niobium improving performance of:
- Capacitors and inductors
- Sensors
- Electric Controls
- Electronic Circuits
- Niobium replacing other hazardous or rare materials

## Better Drivetrain, Brakes & Wheels

- Lighter gearboxes, gears, and transmissions
- More fatigue resistant parts with longer service life
- Reduced wear and part failure
- Lighter and stronger aluminium or steel wheels

## Faster Wireless Charging

- Niobium nanocrystalline materials
- Increased magnetic shielding
- improved efficiency of charging, reducing electrical losses.

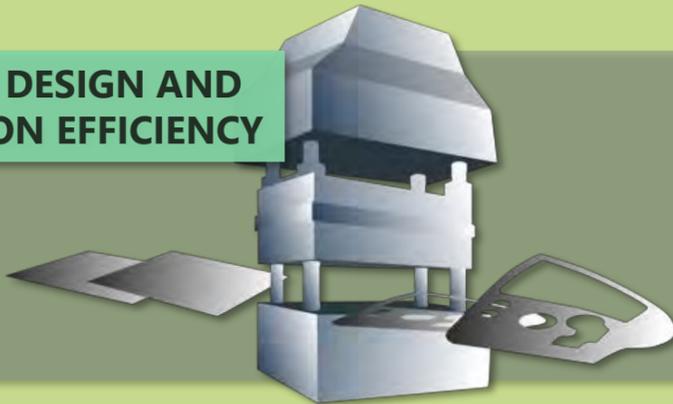


# CBMM NIOBIUM: CREATING VALUE IN AUTOMOTIVE

REDUCED EMISSIONS FROM STEEL PRODUCTION AND TRANSPORT



IMPROVED DESIGN AND PRODUCTION EFFICIENCY



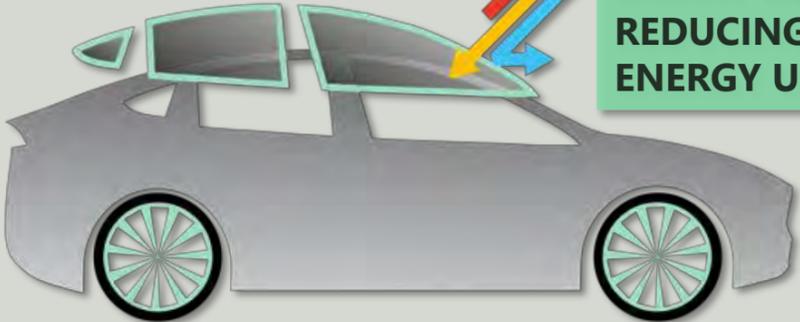
SAFER AND LIGHTER VEHICLES



STRONGER, HARDER WEARING PARTS



STRONGER, LIGHTER COMPONENTS WITH COMPLEX SHAPES



SMART GLASS REDUCING ENERGY USE



LIGHTER CAST PARTS AND HIGHER COMBUSTION PRESSURE



INCREASED ENERGY CAPACITY AND REDUCED CHARGING TIME

IMPROVED FUEL EFFICIENCY AND RANGE

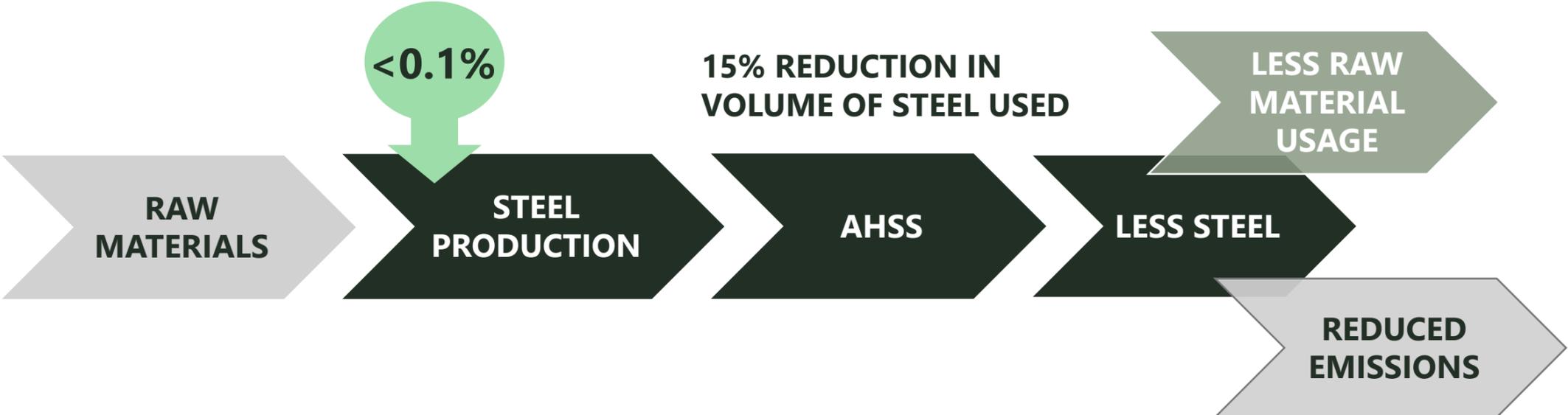


100% RECYCLABLE STEEL WITH INCREASED MATERIALS RECYCLING



# CBMM NIOBIUM: REDUCING THE ENVIRONMENTAL IMPACT OF MATERIAL PRODUCTION

ADDITION OF LESS THAN 0.1% NIOBIUM  
TO TRANSFORM STEEL PROPERTIES



EVERY TONNE LESS IRON ORE USED  
= 2 TONNES REDUCTION IN CO<sub>2</sub>

NIOBIUM IS THE MICROALLOYING ELEMENT  
WITH LOWER LCA IMPACT

7-20x LESS CARBON DIOXIDE  
THAN OTHER MATERIALS



# **BRAKE IMPROVEMENT OPPORTUNITIES**

Introduction to Niobium Brakes

# BRAKE IMPROVEMENT OPPORTUNITIES

## PERFORMANCE



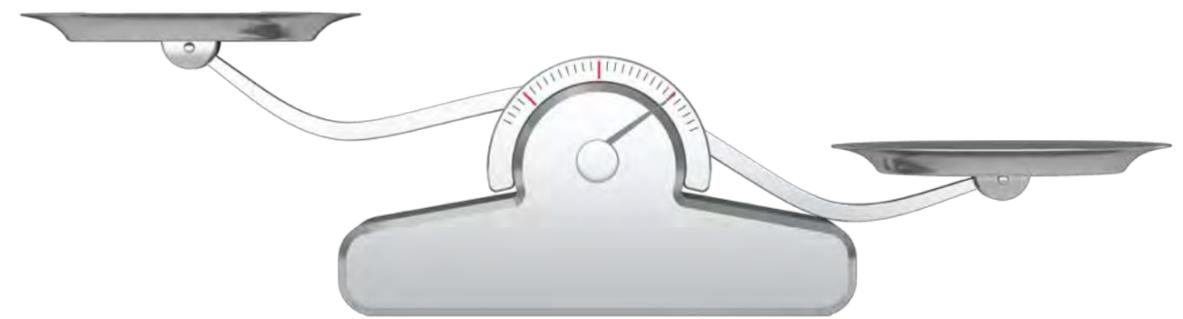
## COPPER-FREE

## AESTHETICS & NOISE



## CORROSION

## LIGHTWEIGHTING



## ECONOMICS

# AFTER MARKET - FORD F150: TWO KINDS OF BRAKE DISC

Compare Item



**FREE NEXT DAY**

✓ Fits Your Vehicle

**Duralast Brake Rotor**

Price: **\$89.99**

Location: Front  
Warranty: **2 years**  
Notes: Rotor only  
\*Coated on hat and edge for rust prevention \*Replace in pairs for best performance

Compare Item



**FREE NEXT DAY**

✓ Fits Your Vehicle

**Duralast Gold Brake Rotor**

Price: **\$115.99**

★★★★★ (8)  
Part Number: 42251DG  
Location: Front  
Warranty: **3 years**  
Notes: Rotor only  
\*Higher Carbon Content for maximum heat dissipation, quieter braking, and longer life  
\*Z-Clad coating ...

Compare Item



**FREE NEXT DAY**

✓ Fits Your Vehicle

**Duralast GT Street Brake Rotor**

Price: **\$115.99**

★★★★★ (2)  
Part Number: 42251GT  
Location: Front  
Warranty: **2 years**  
Notes: Rotor only  
\*Unique design to create extra bite for reduced stopping distance

**+29% price** →

**+50% of warranty** →

Price: <b>\$89.99</b>	Price: <b>\$115.99</b>	Price: <b>\$115.99</b>
<p>Duralast® brand disc brake rotors are designed and engineered to match J431 and your vehicle's original equipment performance. Our Duralast® rotors can replace your OE parts with no change in performance and safety. So when you need a part you can trust at a price you can afford, look for Duralast® rotors at your local AutoZone store.</p> <ul style="list-style-type: none"> <li>Manufactured in TS16949 certified facilities</li> <li>Engineered to reduce brake noise</li> <li>High strength alloy for long life and increased resistance to warping</li> <li>Balanced for smooth stopping and increased resistance to warping</li> </ul>	<p>Duralast Gold® brake rotors utilize a high carbon formulation to minimize noise and enhance performance. The carbon used in rotors dampens noise and dissipates heat. With Duralast Gold® brake rotors, you get quieter brakes without sacrificing performance. Specifically formulated for the toughest braking applications, Duralast Gold® brake rotors are the best choice for ensuring noise free braking. For best results, always use Duralast Gold® brake pads</p> <ul style="list-style-type: none"> <li>High-carbon steel to deliver maximum heat dissipation for improved braking performance</li> <li>Fully coated for superior rust protection</li> <li>Advanced material to reduce noise</li> <li>Higher carbon specification than standard rotors</li> </ul>	<p>Exclusively available at AutoZone, Duralast GT® Rotors are direct replacement brake discs for factory brake systems and stock calipers that look great behind your wheels while offering significantly improved braking performance. The GT® slot allows the Rotors to be installed on either the right or left side, so there is no need to worry about matched rotation. Combine Duralast GT® Rotors with a set of Duralast GT® pads for even better braking performance.</p> <ul style="list-style-type: none"> <li>Direct fit replacement - performance brake Rotors engineered for factory brake systems and calipers</li> <li>GT Jet coat – rust preventive coating designed to withstand 120 hours of salt water exposure</li> <li>GT slot – GT slotting designed to prevent brake pad glazing, increase bite and improve wet braking performance</li> <li>Advanced metallurgy – enhanced with higher carbon content for improved stopping and longer life</li> </ul>

**+Carbon and less noise** →

	Category	Brake Rotor	Brake Rotor	Brake Rotor
Weight		29.65 lbs. (13.48 kgs)	29.65 lbs. (13.68 kgs)	30.42 lbs. (13.83 kgs)
Warranty		<b>2 years</b>	<b>3 years</b>	<b>2 years</b>
Bore Diameter (mm)		90.0	90.0	90.0
Discard Thickness (mm)		32.0	32.0	32.0
Drilled		No	No	No
Initial Thickness (mm)		34.0	34.0	34.0
Orientation		Non-Directional	Non-Directional	Non-Directional

# Nb IN DRUM AND BRAKE DISCS

## IMPROVES RESISTANCE TO CRACKS:

**Nb** allows an increase the thermal conductivity, decreasing the average temperature, bringing good contribution to increase the thermal shock tri-resistance index

## SUPPORTS WEIGHT REDUCTION:

**Nb** Additions up to 0.3% tend to improve the mechanical properties of gray iron resulting from a reduction in the cell size and correspondingly blunt graphite flake size

## ALLOWS IMPROVEMENTS IN FLUID AERODYNAMICS AND DISC COOLING:

**Nb** decreases the tendency to produce chill carbides due to an inoculating effect and the increase in cell count, and will contribute to obtain refined geometry in the disc cooling

## ENCOURAGES BRAKE DESIGN TO AVOID FOREIGN PARTICLES INGRESS:

Better material drives geometry improvement, increasing the desired flow direction

# WORKING TOGETHER TO DEVELOP ROTOR AND DRUM BRAKES...

Understanding the customer's needs

## DEVELOPMENT PHASES



Validation test in laboratory – thermal fatigue



## IN REAL USE



Premature wear.



Premature thermal crack.



## COMPETITIVENESS



New competitors  
New Market Conditions



**... CBMM CAN SUPPORT YOU IN THE ALLOY DEVELOPMENT**



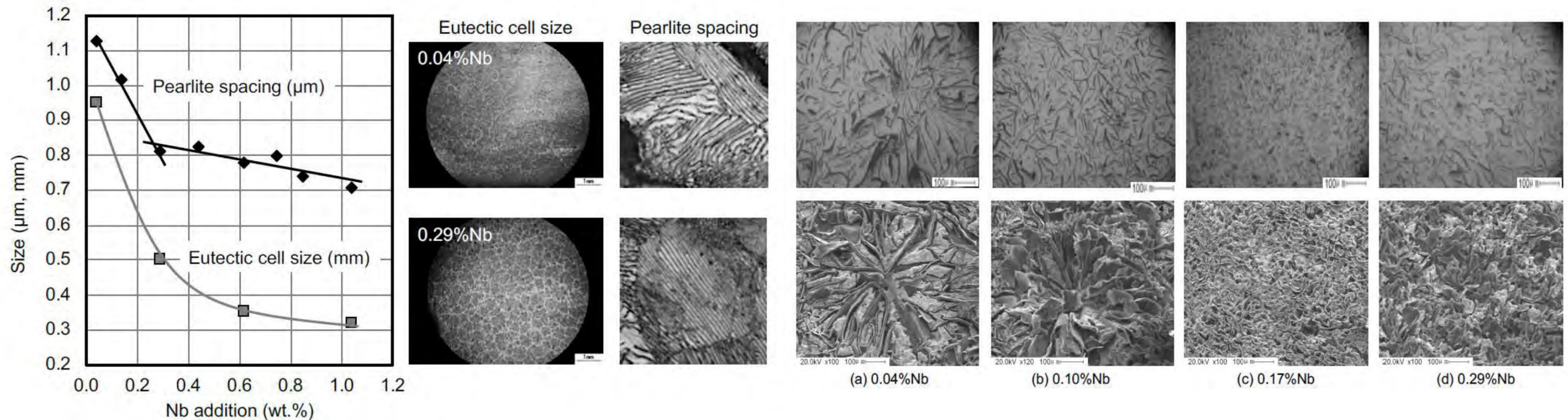
# **BENEFITS OF USING Nb IN BRAKE COMPONENTS**

Introduction to Niobium Brakes



# ROLE OF Nb IN GRAY CAST IRON REFINEMENT

Through refinement of the cast structure, addition of Nb in cast iron will reduce the dimensions of eutectic cells and associated pearlite spacing and graphite flake lengths. The associated strength increment allows for an increase in the carbon equivalency and thermal conductivity at a given strength.

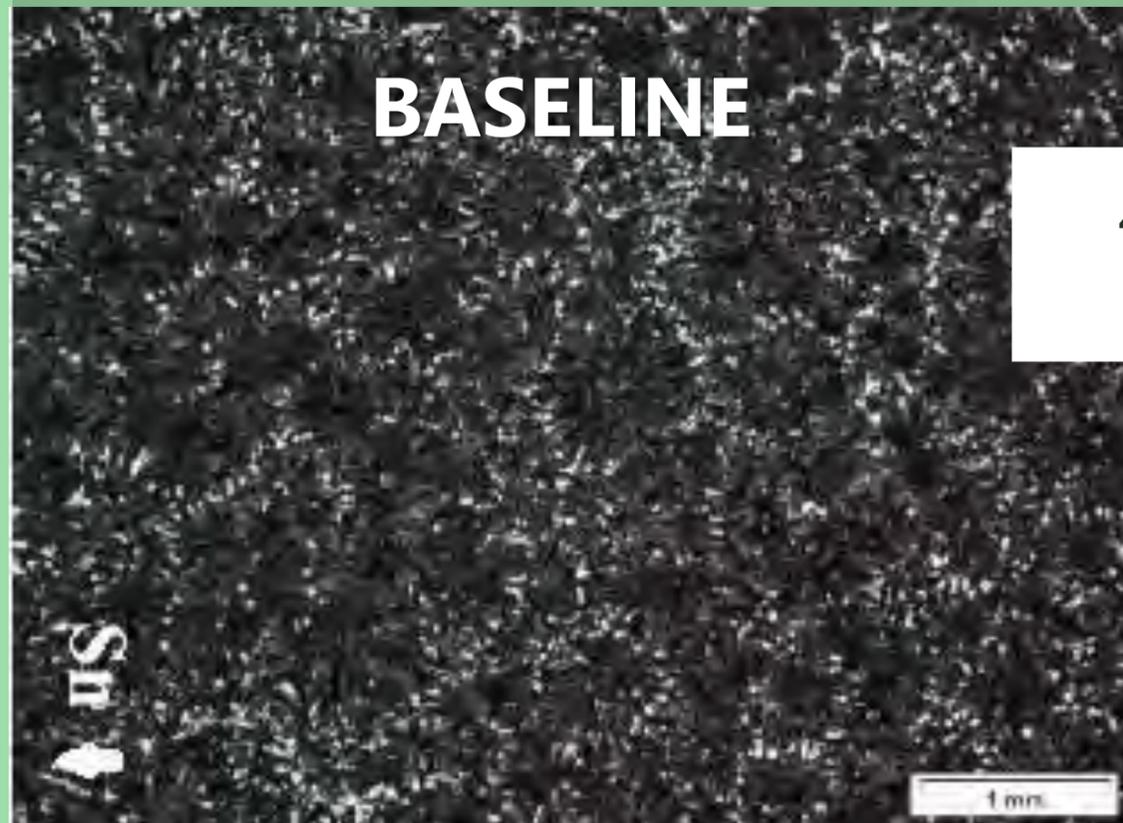


Effect of niobium addition on eutectic cell size, pearlite spacing and graphite morphology in a hyper-eutectic gray iron alloy.

# ROLE OF Nb IN GRAY CAST IRON

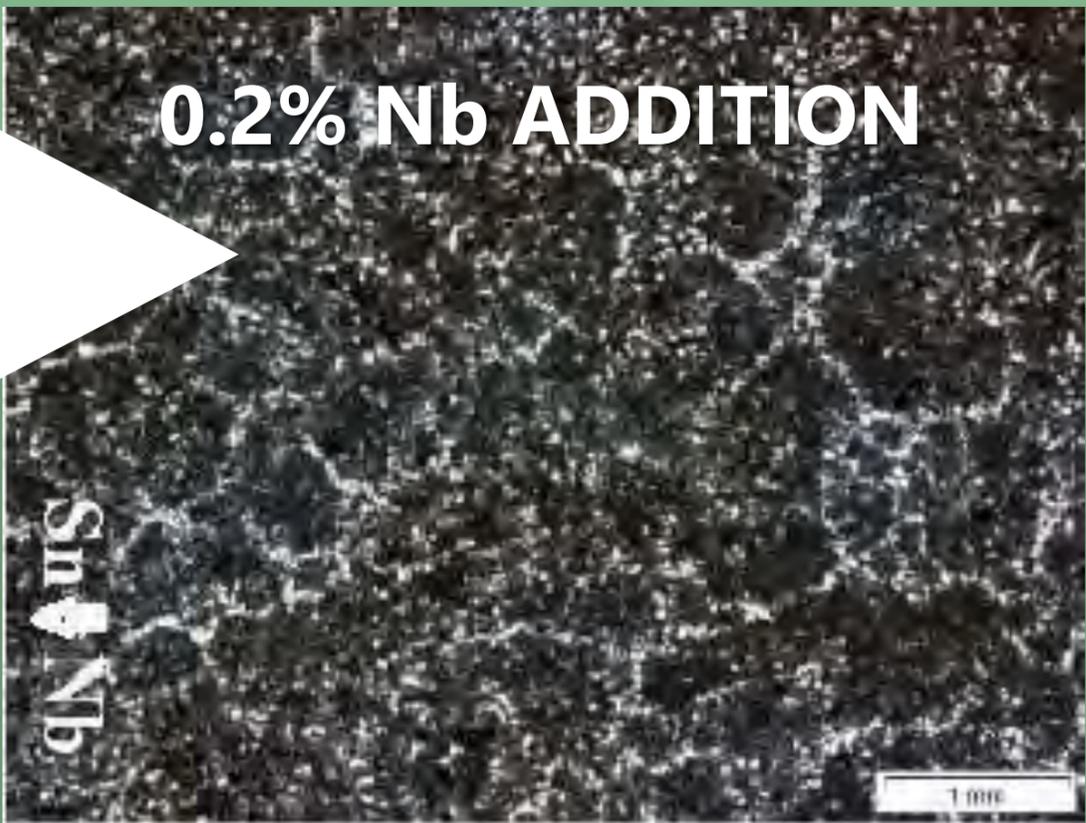
## GRAIN REFINEMENT

Through refinement of the cast structure, addition of Nb in cast iron will reduce the dimensions of eutectic cells and associated pearlite spacing and graphite flake lengths. The associated strength increment allows for an increase in the carbon equivalency and thermal conductivity at a given strength



**BASELINE**

47% Increase in Eutectic Cell Density



**0.2% Nb ADDITION**

### RESULTS

Equivalent Carbon -2.8%\*  
UTS +39.5% MPa  
Hardness +15.1% HB

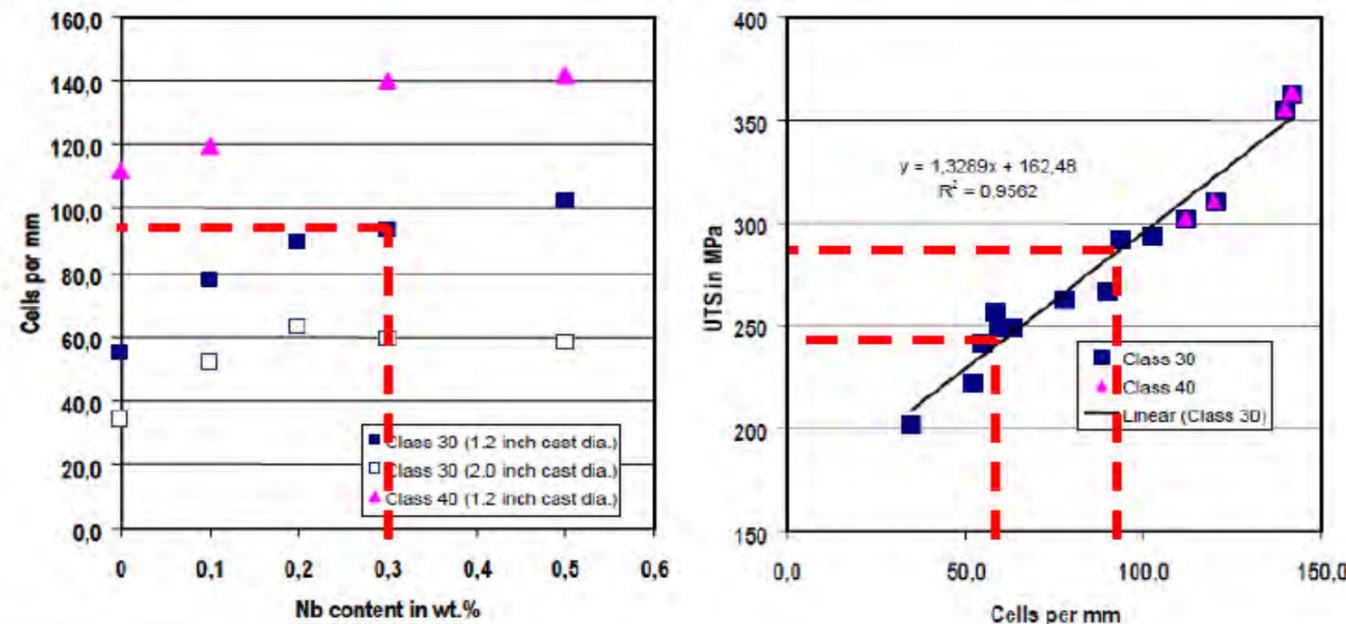
Equivalent Carbon = 4.29  
UTS = 129 MPa / 18,7 ksi  
165 HB

\*Similar CE targeted for comparison and variation due to casting practices

Equivalent Carbon = 4.17  
UTS = 180 MPa / 26,1 ksi  
190 HB

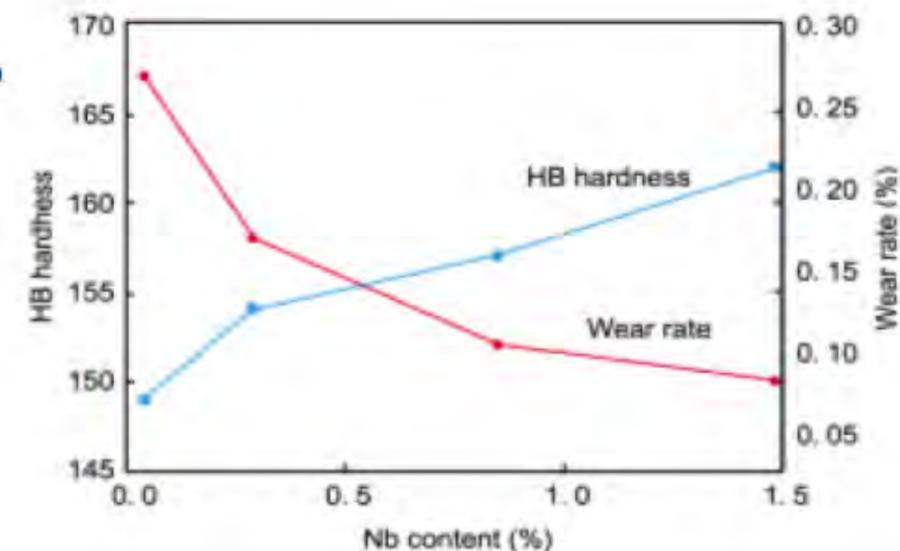
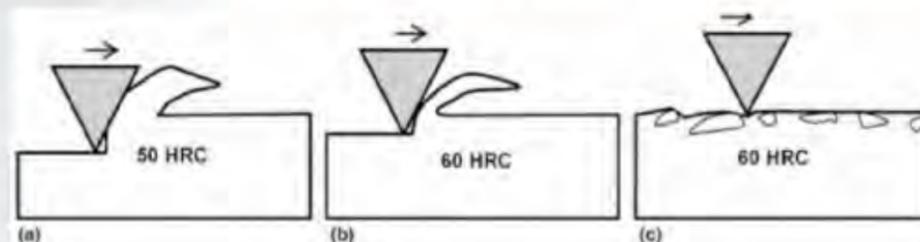
# HIGHER NUMBER OF EUTECTIC CELLS, HIGHER TENSILE STRENGTH PRECIPITATES OF NbC CONTRIBUTES TO REDUCE THE WEAR

- Finer eutectic cells → Higher strength

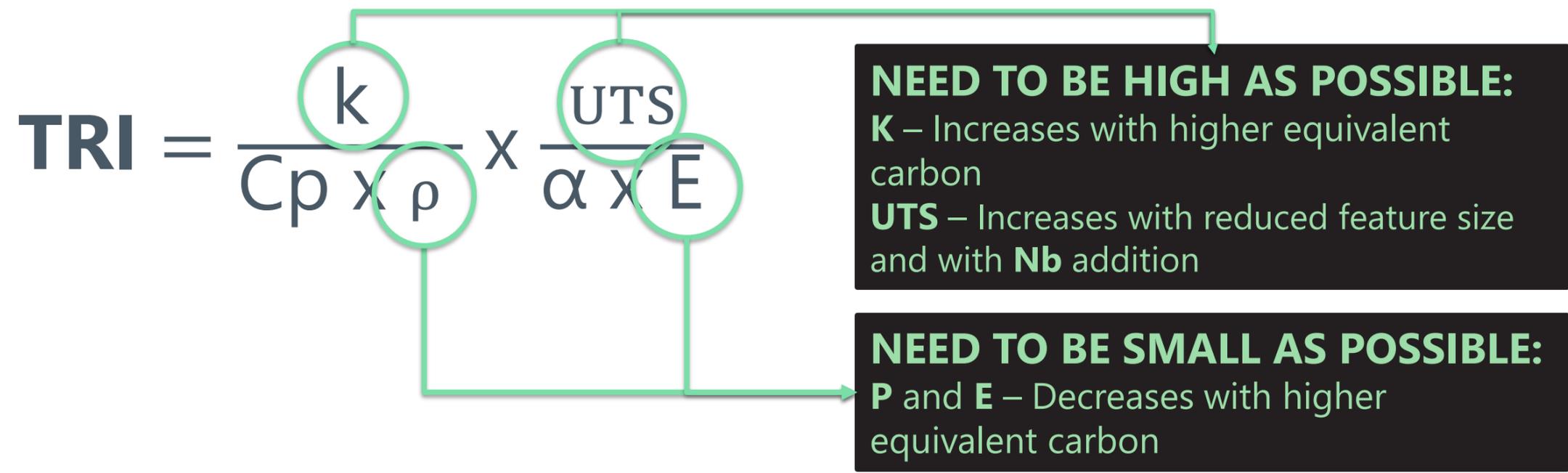


- As an example, an addition of 0,3% of Nb results in a gain of 50MPa/7,25 ksi

- Precipitates of NbC → Better wear resistance



# HIGHER TRI: THERMAL SHOCK RESISTANCE INDEX



Where, TRI = Thermal Shock Resistance Index

**k** = Thermal conductivity

**Cp** = Specific heat of the material

**ρ** = Density

**UTS** = Resistance Limit

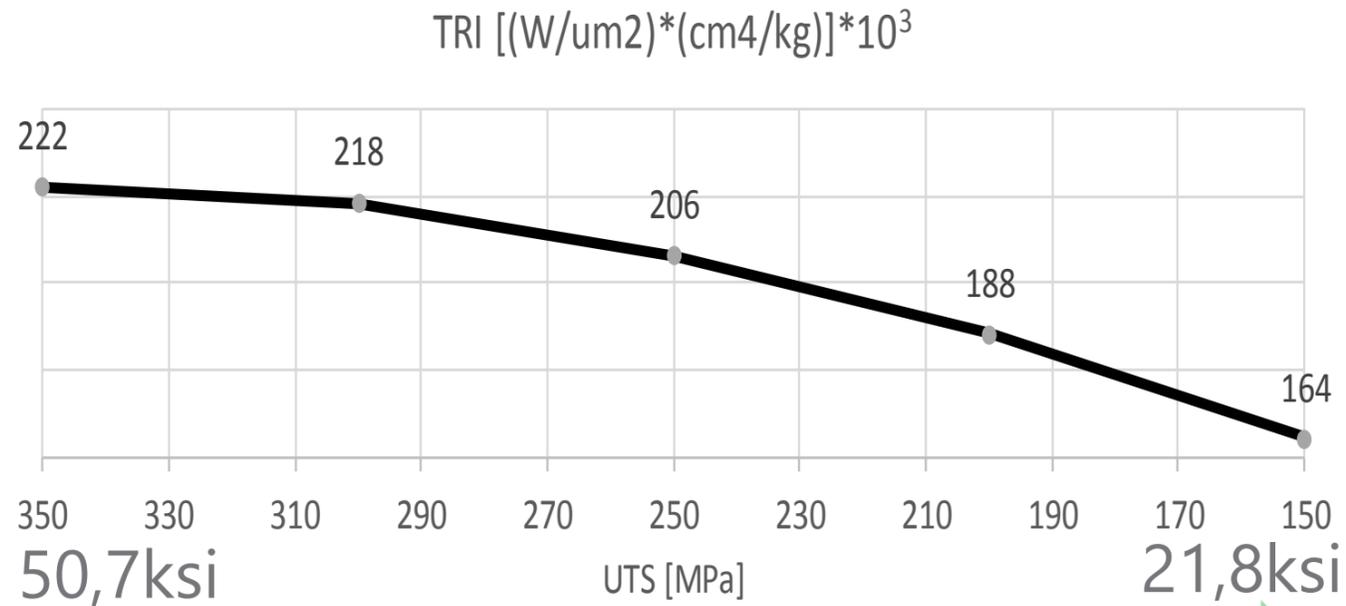
**α** = Expansion coefficient

**E** = Modulus of elasticity

**STRUCTURAL REFINEMENT LEADS TO A HIGHER TRI AND TO BETTER THERMAL FATIGUE RESISTANCE**

WHEN INCREASING THE EQUIVALENT CARBON, THE UTS WILL DECREASE; HOWEVER, BY ADDING Nb, THE UTS IS RECOVERED AND/OR INCREASED.

# THE INFLUENCE OF Nb IN THE TRI

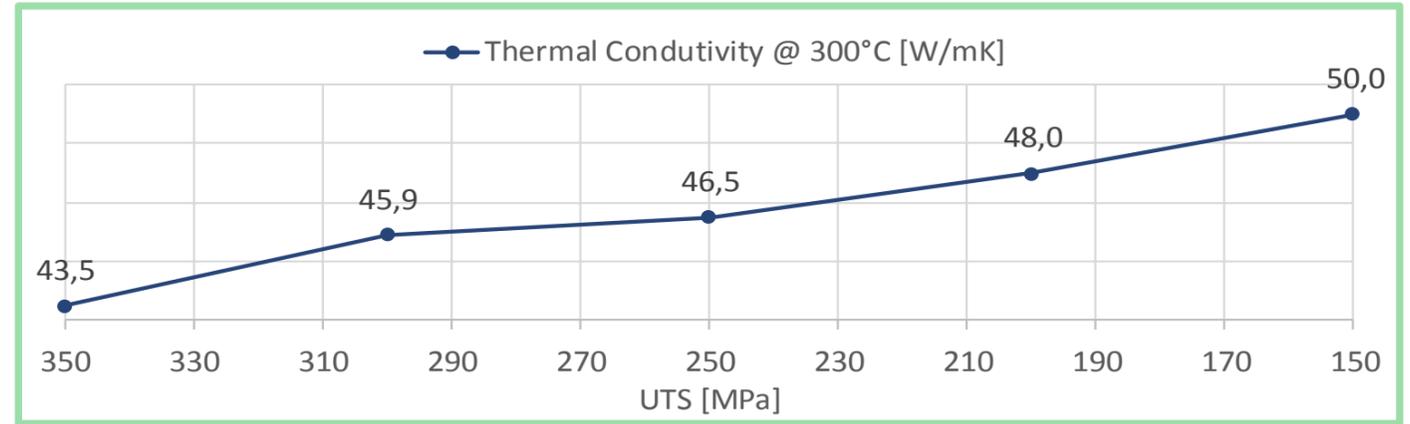


LOW EQUIVALENT CARBON HIGH

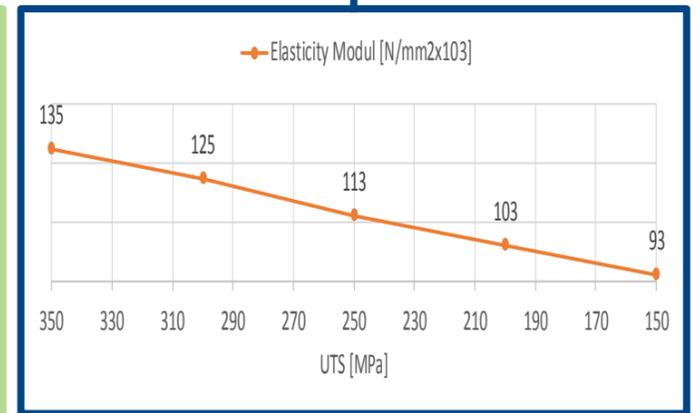
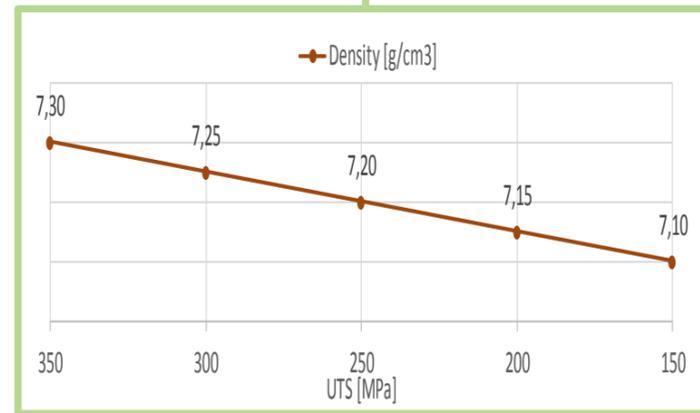
INFLUENCE OF +0,2% Nb WITH SAME CE

CE = 3,99 UTS = 289 MPa / 41,9ksi 218 HB	0% +20% +11%	CE = 3,99 UTS = 348MPa / 50,5 ksi 242 HB
--	--------------------	--

Nb ADDITIONS IN GRAY CAST IRON ALLOW FOR AN STRUCTURAL STRENGTH INCREMENT IF IT IS NECESSARY TO INCREASING THE CARBON EQUIVALENCY

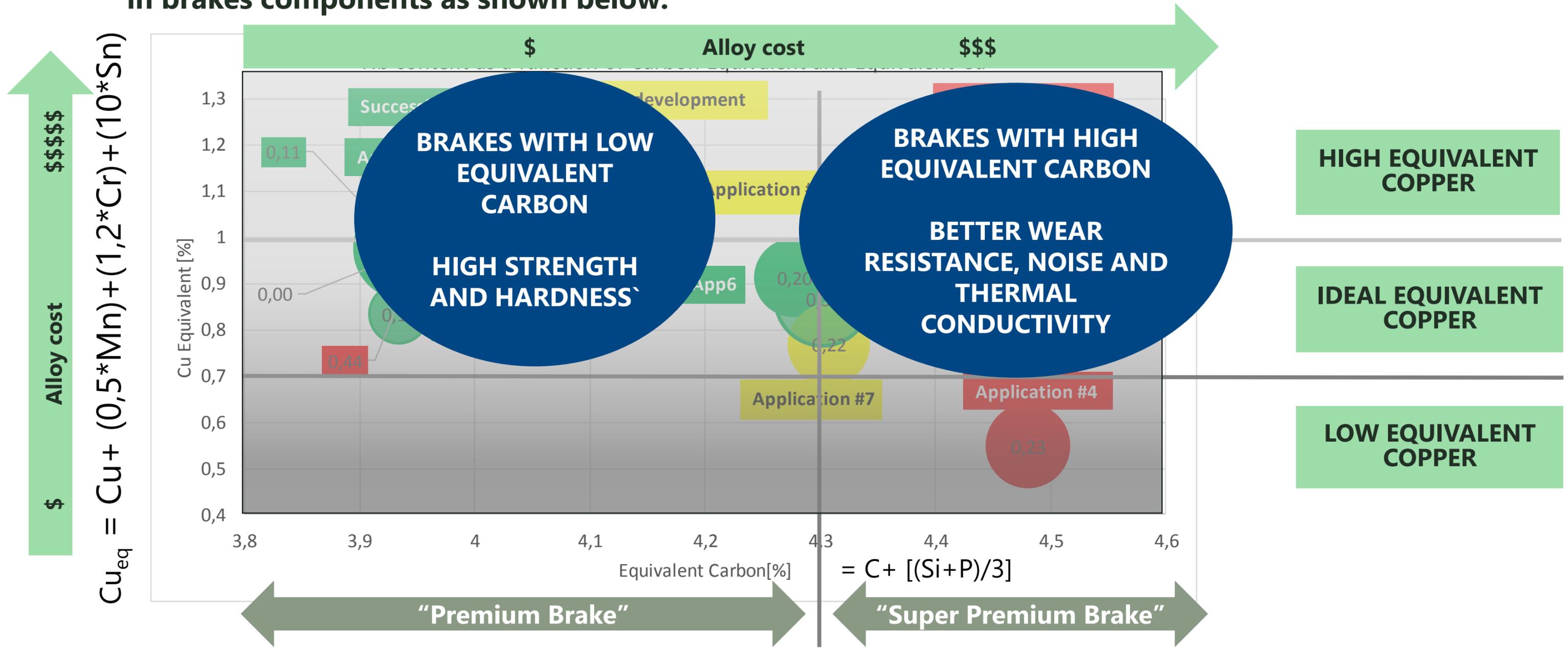


$$TRI = \frac{k}{C_p \times \rho} \times \frac{UTS}{\alpha \times E}$$



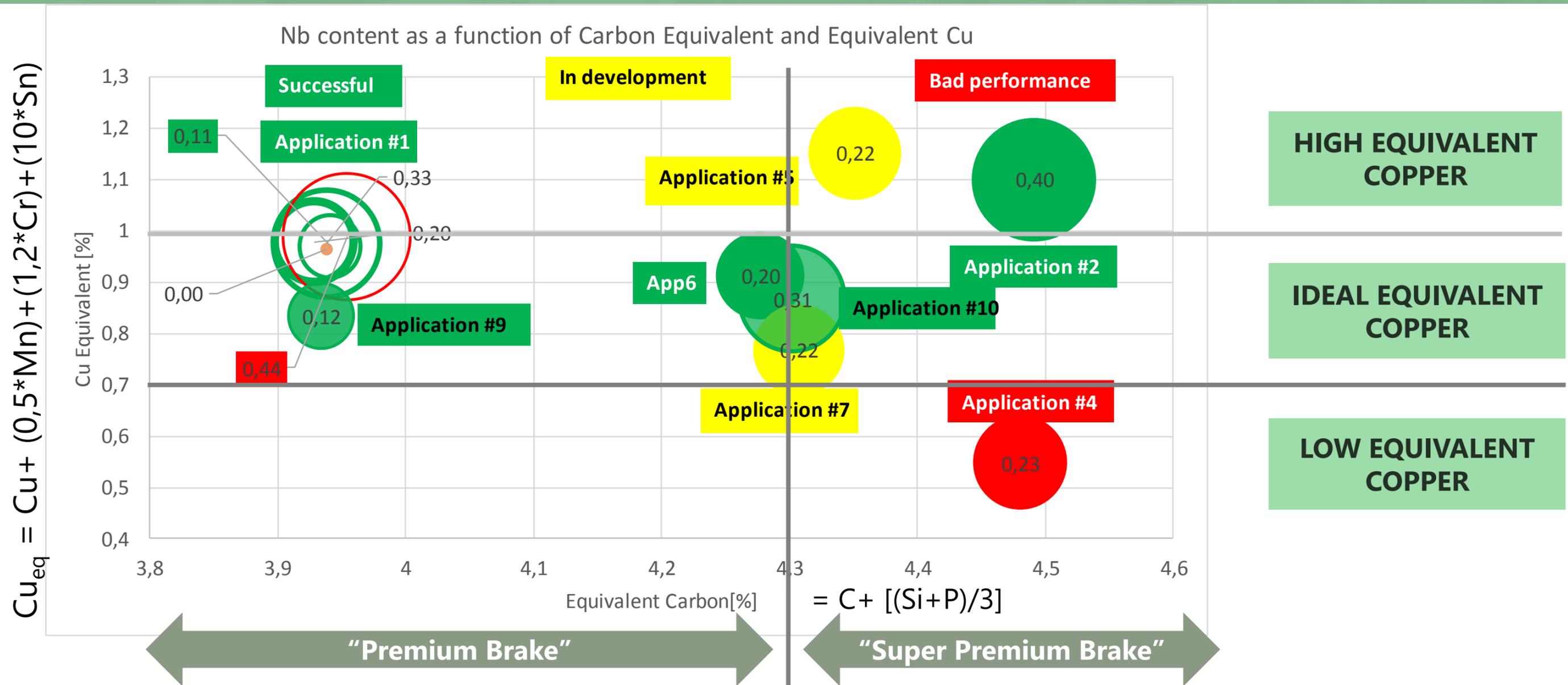
# SEEKING THE SOLUTION ...

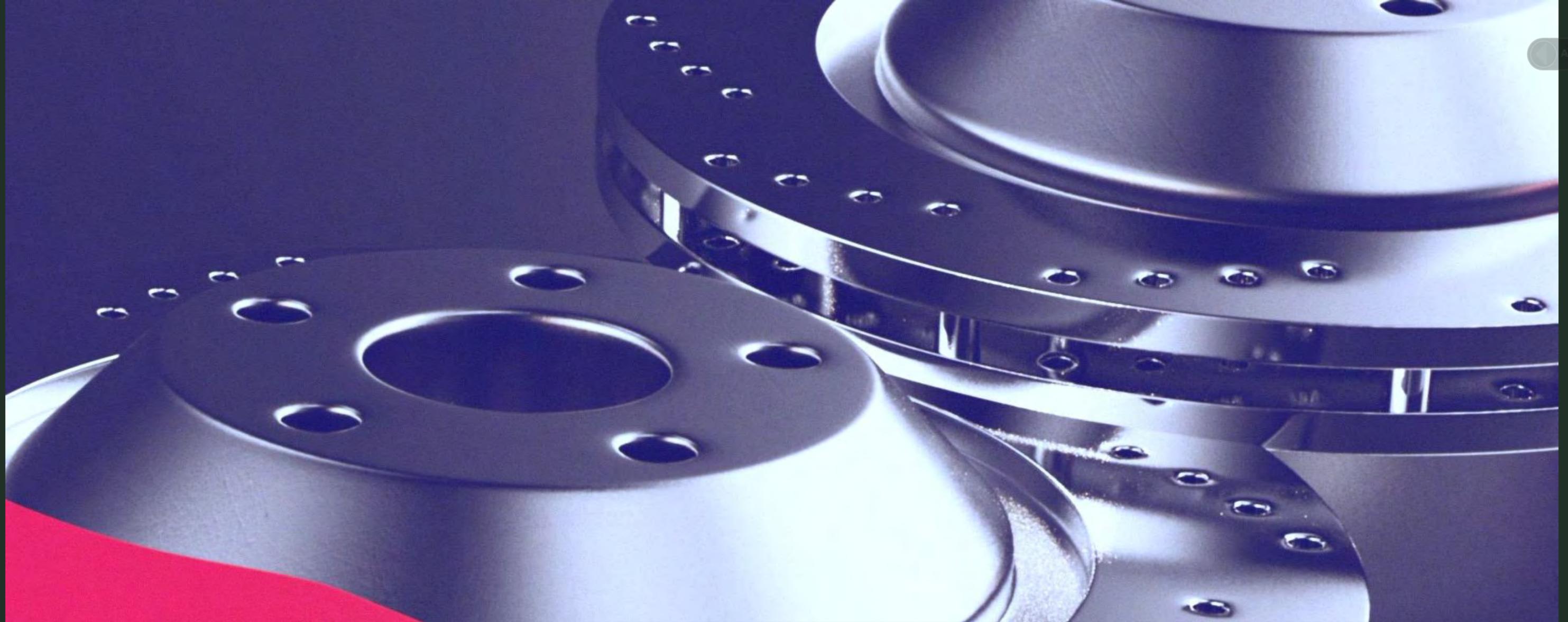
- CBMM's collaborative experience instructs the formulation of alloys used in brakes components as shown below:



# CBMM BACKGROUND DATA FOR ROTORS & DRUMS

- Previous studies with **CBMM** may be summarized as shown below with alloys formulations shown by carbon equivalent and copper equivalent ( $cu_{eq}$ ):





# APPLICATION OF FeNb IN BRAKE COMPONENTS

Introduction to Niobium Brakes

# BRAKE ROTOR & DRUM DEVELOPMENT PROCESS PATH



# DEVELOPMENT OF BRAKE ROTOR WITH NIOBIUM

## THERMAL FATIGUE TEST WITH SUCCESSIVE ACCELERATION AND BRAKING

60% REQUESTED LIFETIME



70% OF REQUESTED LIFETIME



105% OF REQUESTED LIFETIME



#1 AND #2 – START OF THE DEVELOPMENT - BASELINE

#3 USING 0,20% OF Nb AND CUTTING THE USE OF MO

Part	C	Si	Mn	P	S	Cu	Cr	Mo	Ni	Sn	Nb	UTS [MPa]	HB
#1	3,7	1,7	0,4	0,03	0,01	0,55	0,17	0,220	0,11	0,03	0	193 a	180 a
#2								0,024			0	205	205
#3								0,016			0,20		

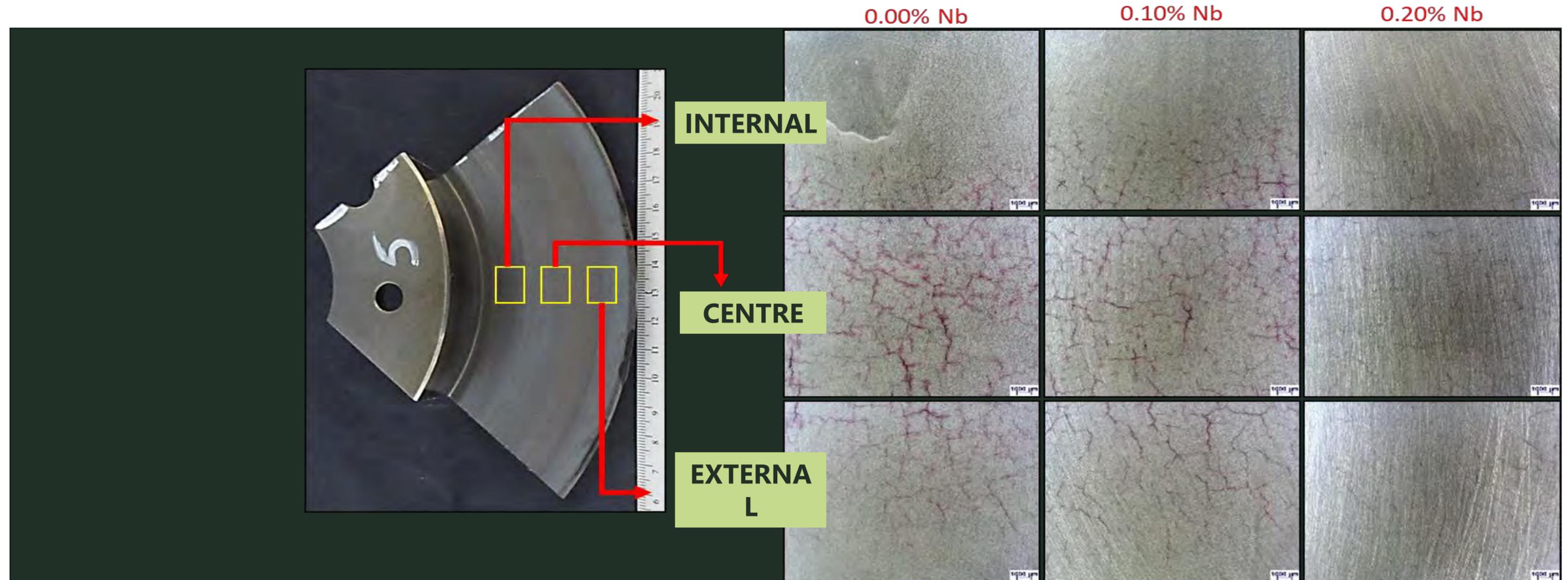
NOTE: ENDURANCE CYCLE: 20 UNTIL 220 KM/H → BRAKE FROM 220 UNTIL 20 KM/H

# ROLE OF Nb

## INCREASING THE THERMAL FATIGUE RESISTANCE

Endurance test – Niobium effect

Crack Distribution Comparison

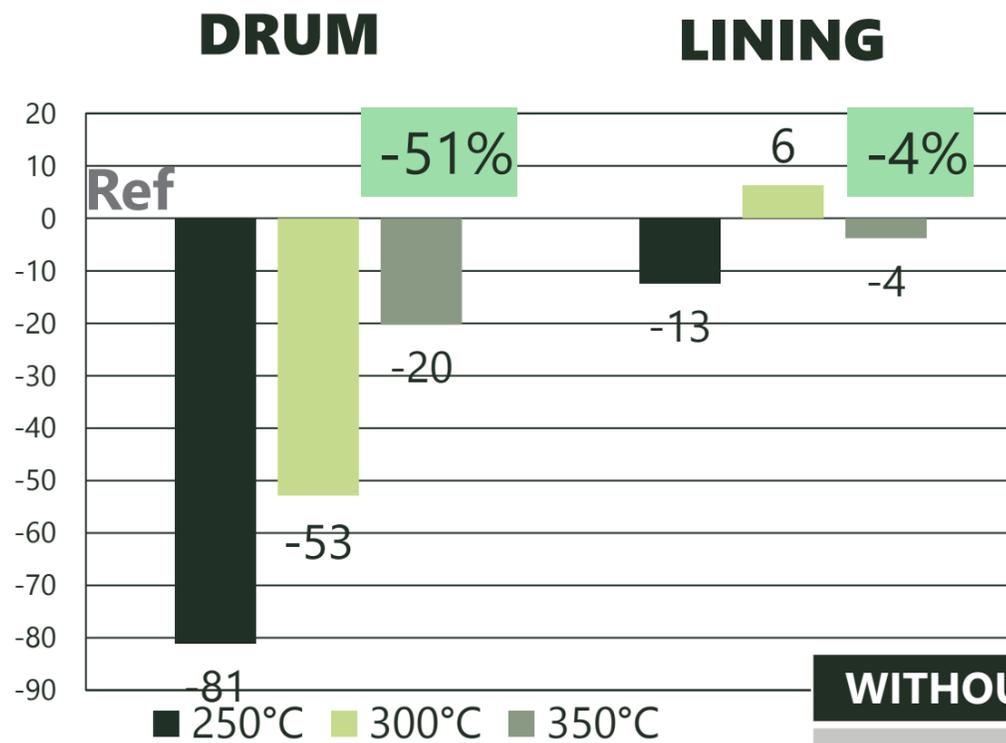


MATERIAL: EQUIVALENT CARBON 3,933 - 3,960%; COPPER EQUIVALENT 0,964 - 1,001 %; UTS 250 MPa

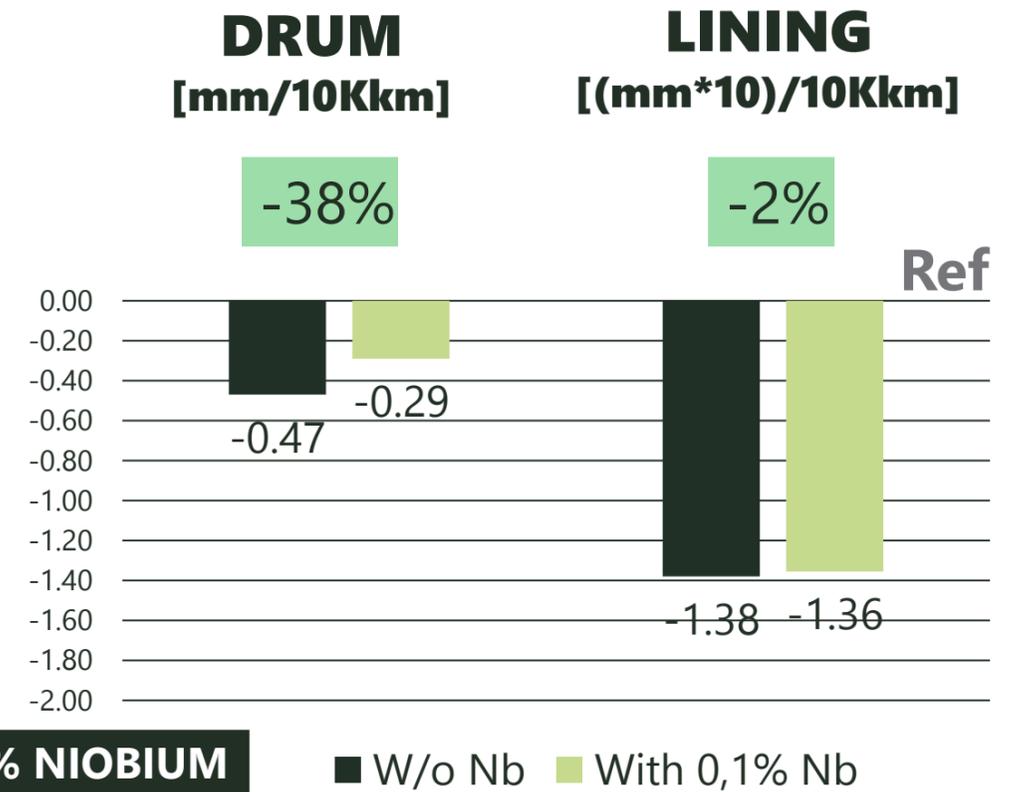
# WEAR BEHAVIOR

## TEST BENCH & ON-VEHICLE ENDURANCE TESTS

**WEAR ON TEST BENCH [%]  
WITH 0.1% Nb x w/o Nb**



**WEAR ON TRAILER**



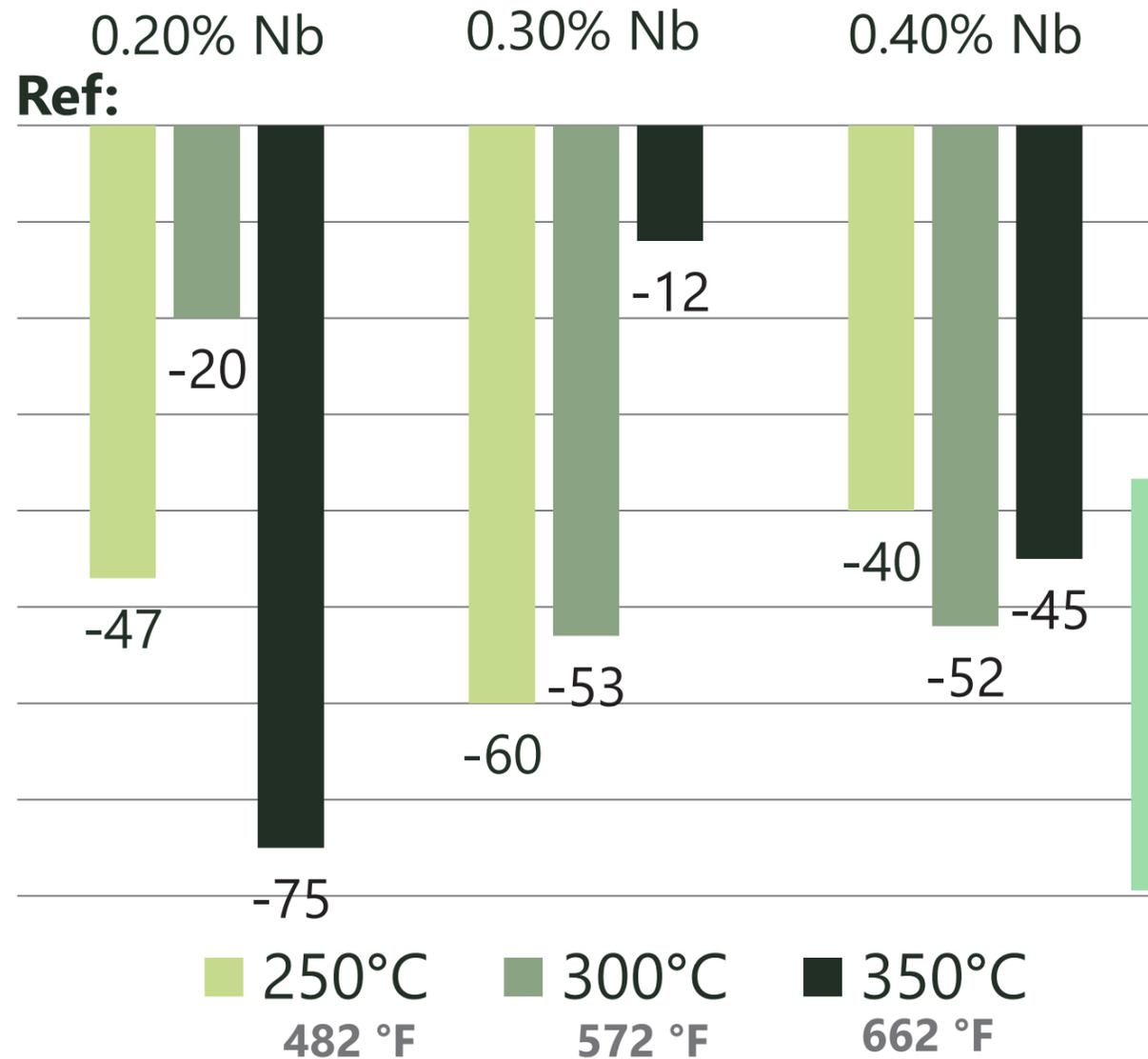
WITHOUT NIOBIUM	CHARACTERISTIC	WITH 0.1% NIOBIUM
3.99	EQUIVALENT CARBON	3.83
0.675	COPPER EQUIVALENT	0.652
285	UTS (MPa)	313
195	HARDNESS (HB)	198

# WEAR BEHAVIOR

## TEST BENCH (BRAKE DISCS, PADS)

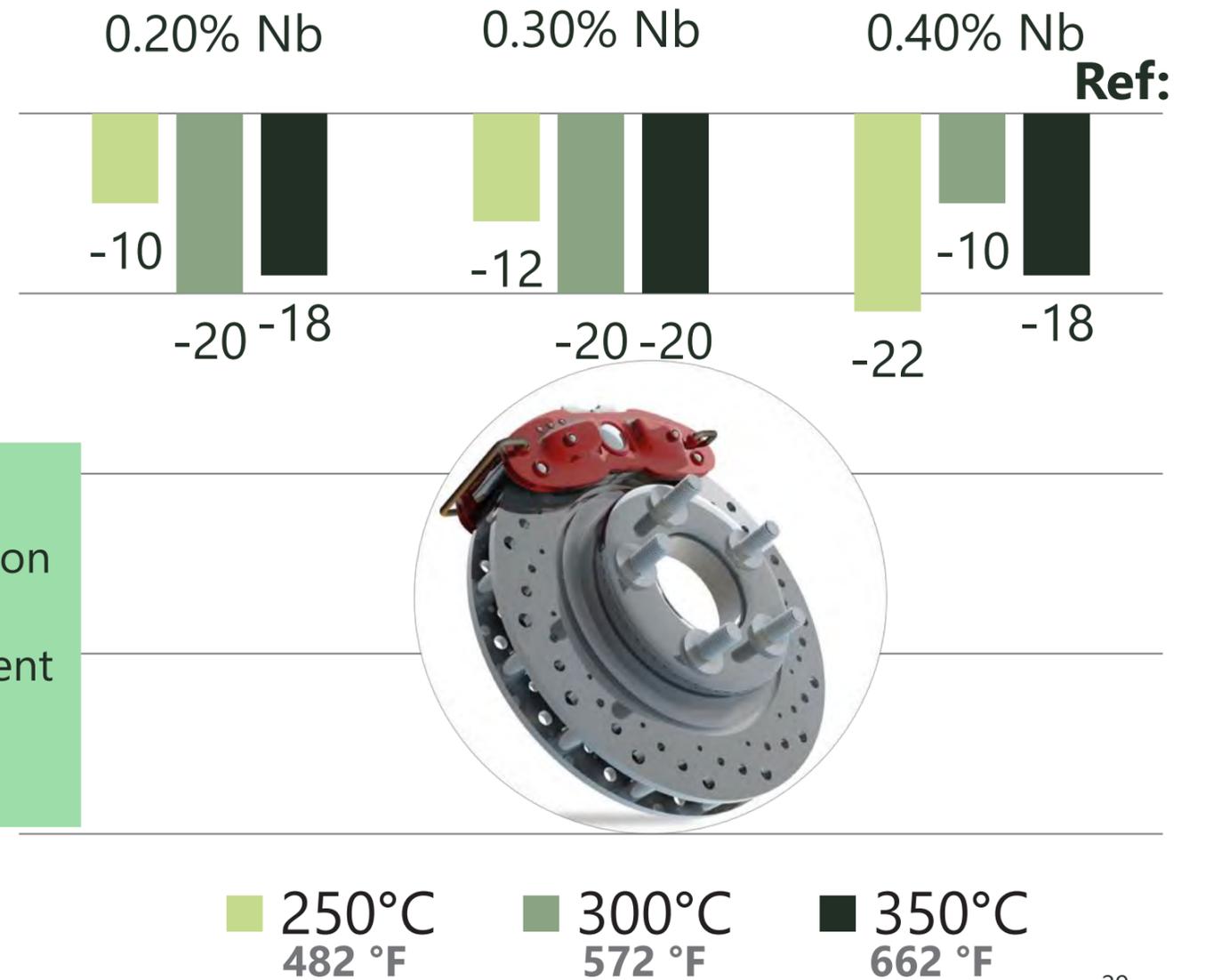
### ROTOR WEAR [%]

ROTOR WITH X,XX% Nb x w/o Nb



### PAD WEAR [%]

ROTOR WITH X,XX% Nb x w/o Nb



**Material:**  
Equivalent Carbon 3,933 - 3,960%;  
Copper equivalent 0,964 - 1,001%;  
UTS 250 MPa



# LIGHTWEIGHT SIMULATION

## CONCEPT

REDUCE THE WEIGHT OF AN ELECTRIC VEHICLE BRAKE DISC BY UTILIZING REGENERATIVE BRAKING AND NIOBIUM-ENHANCED CAST IRON



## BENEFITS

- COST-EFFECTIVE WEIGHT REDUCTION
- INCREASED HARDNESS (LESS WEAR, LESS EMISSIONS)
- NO CHANGE TO FRICTION MATERIALS
- NO NEW SUPPLY CHAIN; STILL AN IRON CASTING
- PROVEN IN PRODUCTION

## METHOD

CONTROL	REDUCED DIAMETER	REDUCED THICKNESS
Original	303mm	30mm
Modified	-6 mm	-1 mm
Original weight	8.45 kg	8.45 kg
Proposed Weight	8.06 kg	8.09 kg
Weight reduction	4.54%	4.24%
Torque loss, on diameter	2%	0%

Note : Mass reduction based on 2013 Chevy Impala disc in CAD; new geometry not tested.

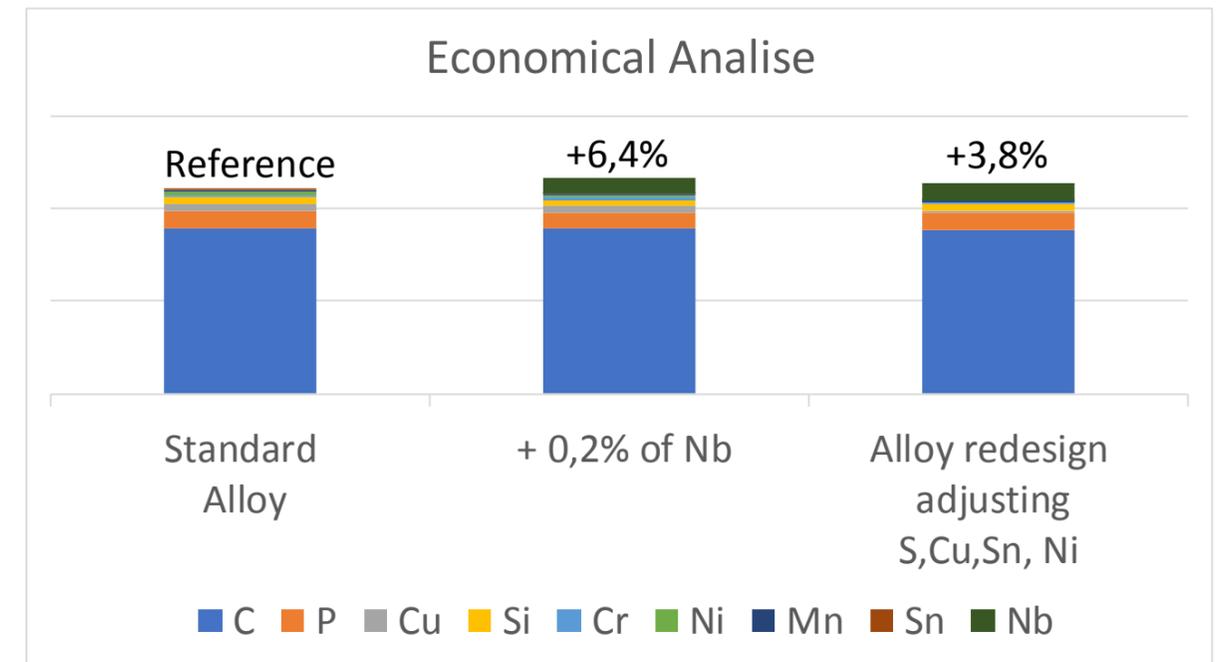
## NEXT STEPS

- OPTIMIZE ALLOY COMPOSITION
- UNDERSTAND OEM POSITION ON REGEN BRAKING
- CASTING TRIAL
- FRICTION SELECTION, EVALUATE COPPER-FREE PADS
- BRAKE TESTING
- WEAR, EMISSION TESTING

# THE REDUCTION OF S, Cu, Sn, AND Ni HAS DEMONSTRATED GOOD PROSPECTS FOR DEVELOPMENT AND THE POSSIBILITY OF SEEKING ECONOMIC OPTIMIZATION IN GRAY CAST IRON ALLOYS

Sample	Chemical Composition											Tensile strength [MPa]	Hardness [HB]
	%C	%Si	%Mn	%P	%S	%Cr	%Cu	%Nb	%Sn	%Ti	%Ni		
7.2	3,78	1,79	0,49	0,03	0,10	0,17	0,62	0,01	0,01	0,03	0,14	119	147
8.2	3,75	1,79	0,49	0,03	0,10	0,18	0,59	0,23	0,01	0,03	0,14	+20 139	+13 160
9.2	3,73	1,70	0,48	0,03	0,04	0,19	0,23	0,01	0,01	0,02	0,01	189	187
10.2	3,70	1,81	0,47	0,03	0,04	0,17	0,23	0,22	0,01	0,03	0,01	+36 225	+13 200

- Nb could contribute to increase the tensile strength and hardness in both applications ( #7.2 x 8.2 and #9.2 x 10.2)
- The gray cast iron, with reduction of S, Cu, Sn and Ni, presented better mechanical resistance and show possibilities to improves alloys where the cost reduction is wanted.



metal prices based in the [http://www.leonland.de/elements\\_by\\_price/en/list](http://www.leonland.de/elements_by_price/en/list)



# CONCLUSIONS

Introduction to Niobium Brakes

# CONCLUSIONS

## THE APPLICATION OF NIOBIUM IN GRAY CAST IRON HAS THE FOLLOWING DEMONSTRATED BENEFITS:

- Increased number of eutectic cells per unit volume during casting for reduced structural feature sizes in gray cast iron, especially for application in components of the brake system
- Increased resistance to mechanical and thermal fatigue, and reduced wear

For each specific application, it is necessary to balance the original alloy composition for targeted mechanical and thermal properties

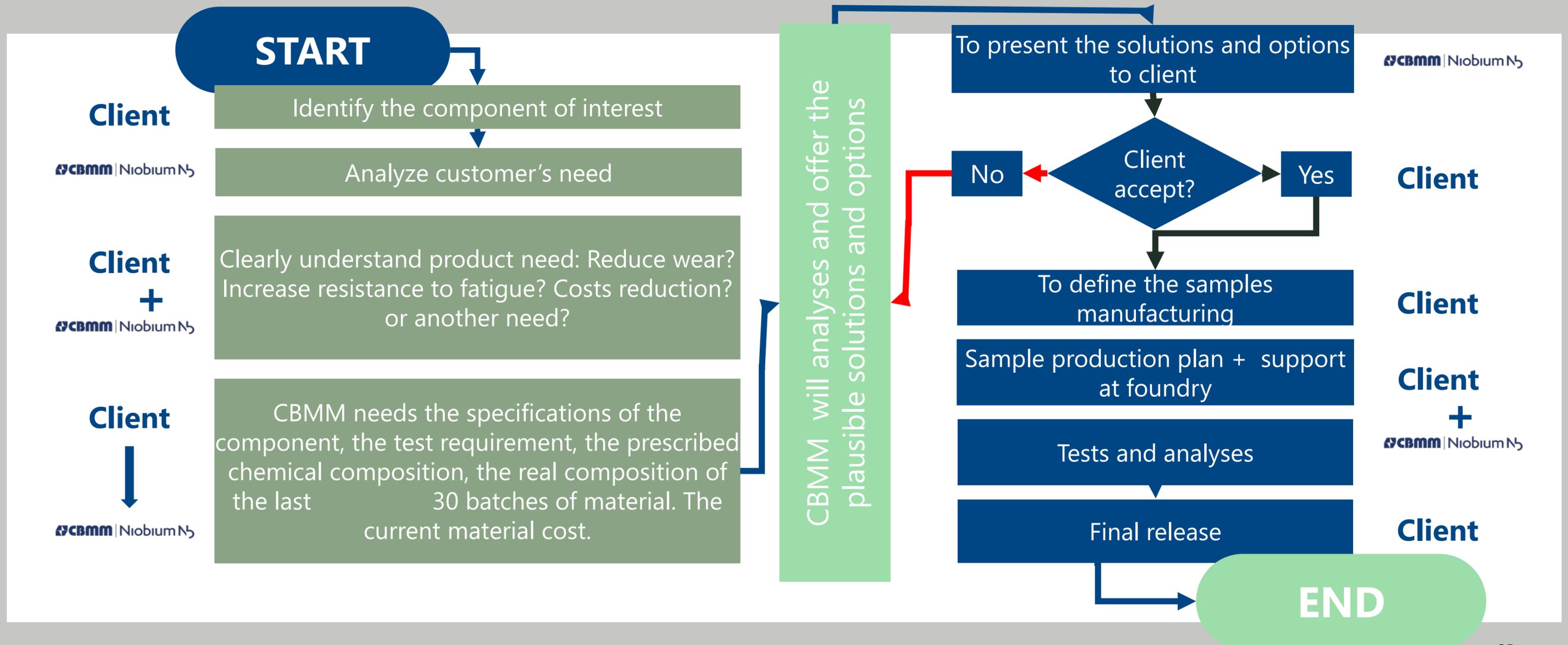
Global **CBMM** technical support includes advice on alloy composition and facilitating the process through initial development, testing, foundry, and qualification



# DEVELOPMENT OF BRAKE COMPONENTS WITH CBMM

Introduction to Niobium Brakes

# HOW TO START THE DEVELOPMENT OF BRAKE COMPONENTS WITH CBMM?



# THANK YOU

For more information contact:  
**[technology@cbmm.com](mailto:technology@cbmm.com)**  
Or visit:  
**[www.niobium.tech/brakes](http://www.niobium.tech/brakes)**

 **CBMM** | Niobium 

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