Recent developments in magnetic materials at Magnequench

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Outline

1. Magnequench Overview
2. Recent Developments in Material
   - Advanced Quenching (AQ) Powders
   - Low Cost and High Temperature Cerium Powders
   - Fully Dense Magnets

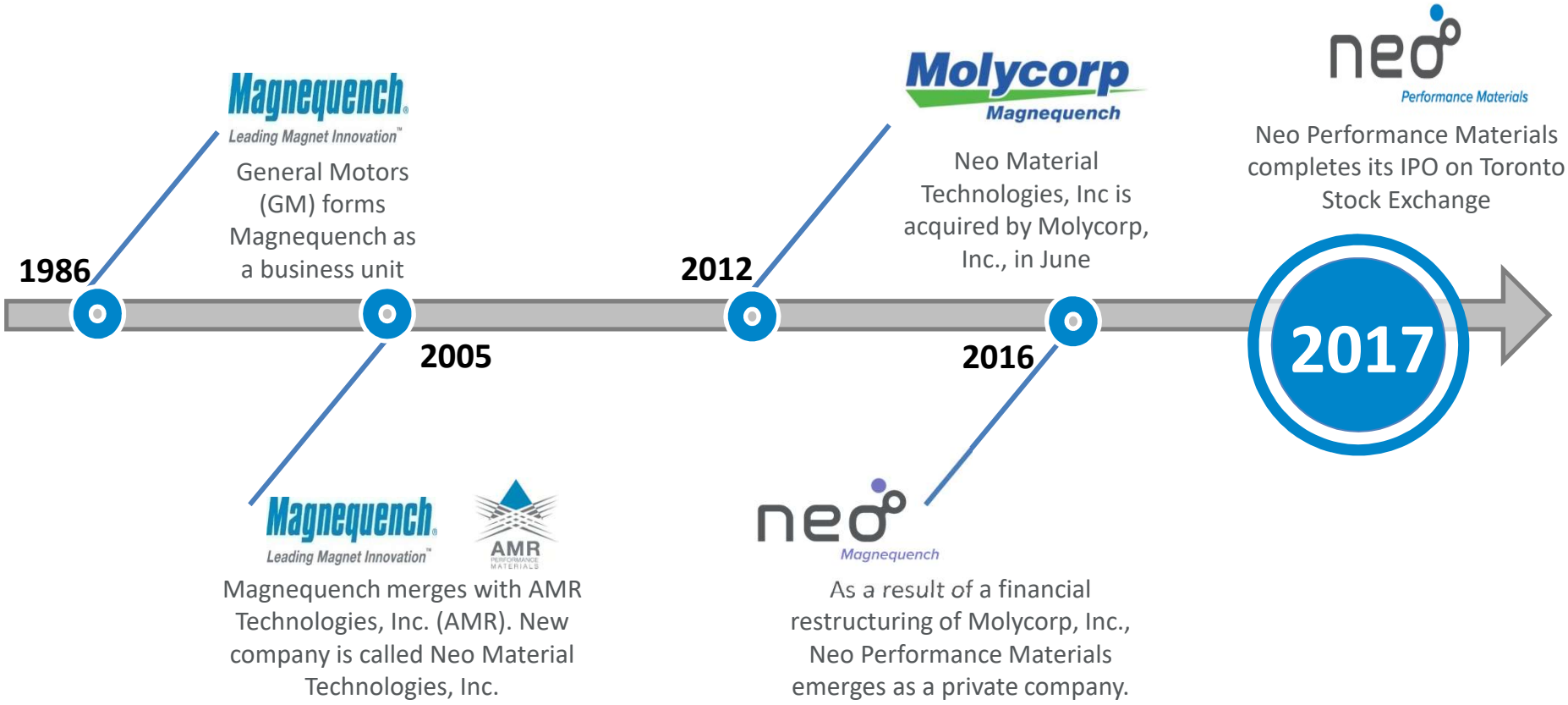
About Magnequench (MQ)

Magnequench is part of Neo Performance Materials, a public limited company listed on Toronto stock exchange with over 35 years of experience and leadership in the rare earth and rare earth metal industries.

#1 Global Market Leader of powders for bonded and hot deformed magnets

Magnequench History

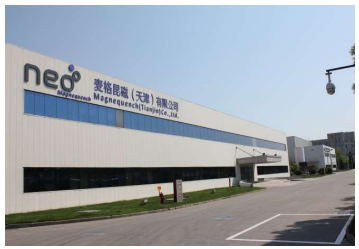
Magnequench has evolved from a GM business unit into a leader of bonded neo magnetic solutions with a global footprint



Magnequench Manufacturing Facilities

- Only supplier in bonded neo powder industry with multiple locations
- Both facilities located in close proximity to customers and raw material sources and within low cost environments

MQTJ (Tianjin, China)



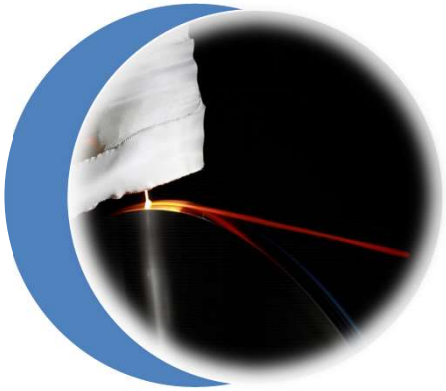

- Capacity – 8,000MT
- 480 employees
- 8 alloy furnaces
- 12 jet casters

MQK (Korat, Thailand)

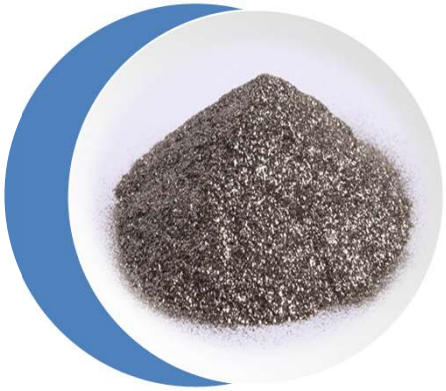

- Capacity – 2,000MT
- 134 employees
- 3 Alloy furnaces
- 3 jet casters

Magnequench Powders

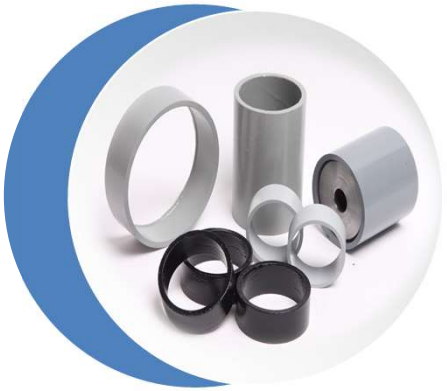
MQ manufactures powder for both bonded (MQ1™) & fully dense anisotropic magnets (MQ3™)



"Jet Casters" rapidly solidify Nd-Fe-B alloys



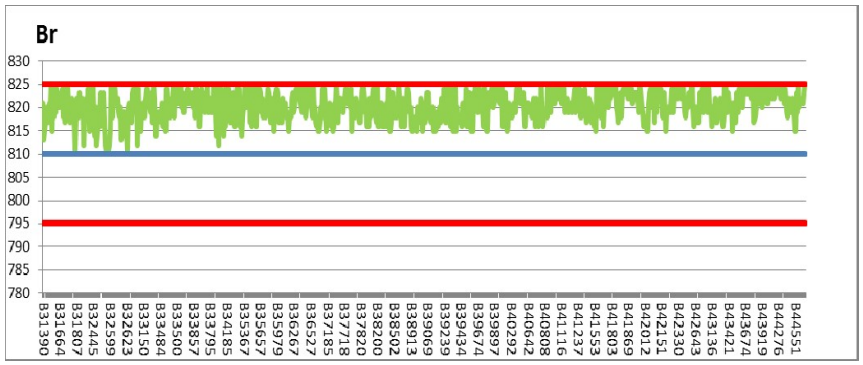
Resulting powder (MQP™) has desired crystalline structure



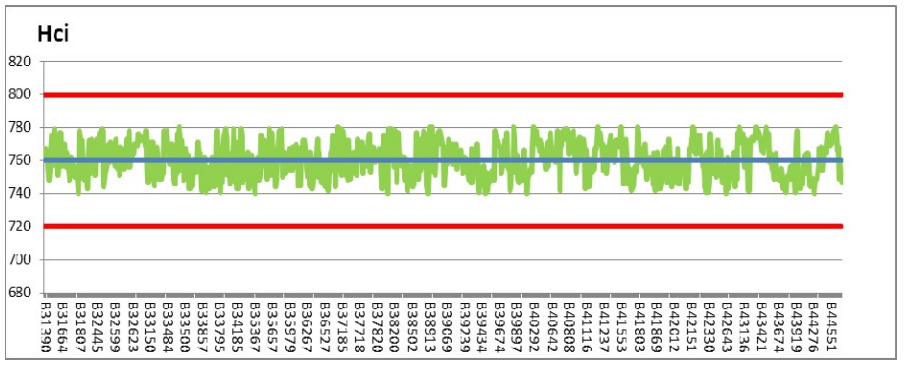
Bonded & Fully Dense Anisotropic magnets are then made from MQ powder

Magnequench's Quality Culture

- Only supplier with a 30 year track record & multiple facilities
- Deep understanding of all relevant quality standards
  - ISO Certifications
- Narrowest powder specifications and most consistent properties, which directly translates to better magnets
  - The more stable the powder lot to lot, the more stable the bonded magnets, this is vital for high volume motors



Br requested to be 'high and narrow'

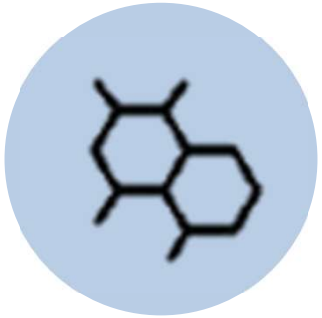


Hci requested to be stable and middle of specification

Value-Added Products (Selected)

MQFP (Fine Powder)

- Helps enable auto pumps by increasing loading
- Improves B_r and aging properties



MQEP Tailoring

- Ready to press; Improve B_r
- Eliminates customer process step

Value-Added Products

AA4 Treatment (Anti-Aging)

- Enables use in "high temperature" automotive applications

PSD Tailoring (Particle Size Distribition)

- Eliminates customer process step

Magnequench Market Development

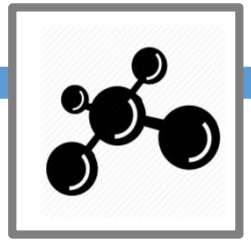
At Magnequench, we work with magnet users to design novel magnetic solutions and to ensure those solutions are executed and supplied with the highest quality.

TRANSLATE

Translate magnet drawing and/or motor performance into material / magnet design concept at ideal cost performance

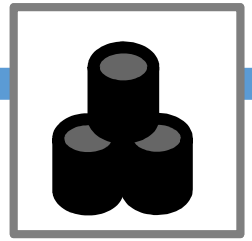
CREATE

Create magnetic powders with guaranteed quality and consistency



BIND

Use Ideal epoxy binder system to enable cutting edge magnet manufacturability at standard production costs



DESIGN

Model and build magnetizing fixture to achieve optimum magnetization profile

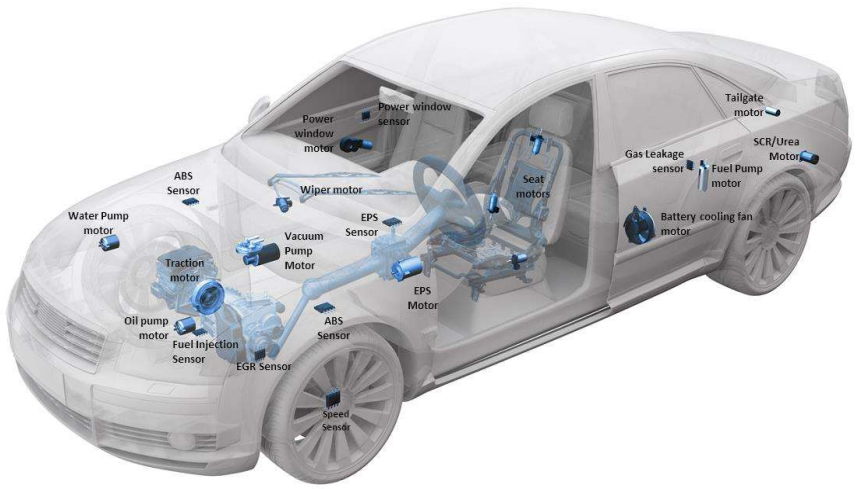
VALIDATE/ DELIVER

Validate/Deliver required Motor performance and magnet

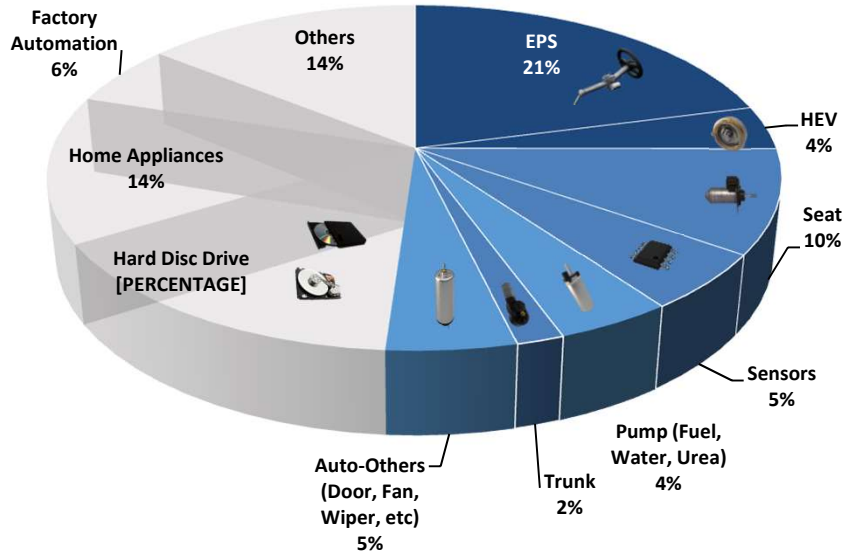
MQ powder products applications

Over 50% of MQ powder sold is used in automotive applications

- Greater demand for increased passenger comfort and functionality
- Automotive industry push towards “Electrification”
- Demand for high efficiency, light weight, and compact electric motors in cars



Applications using MQ magnetic materials within a car

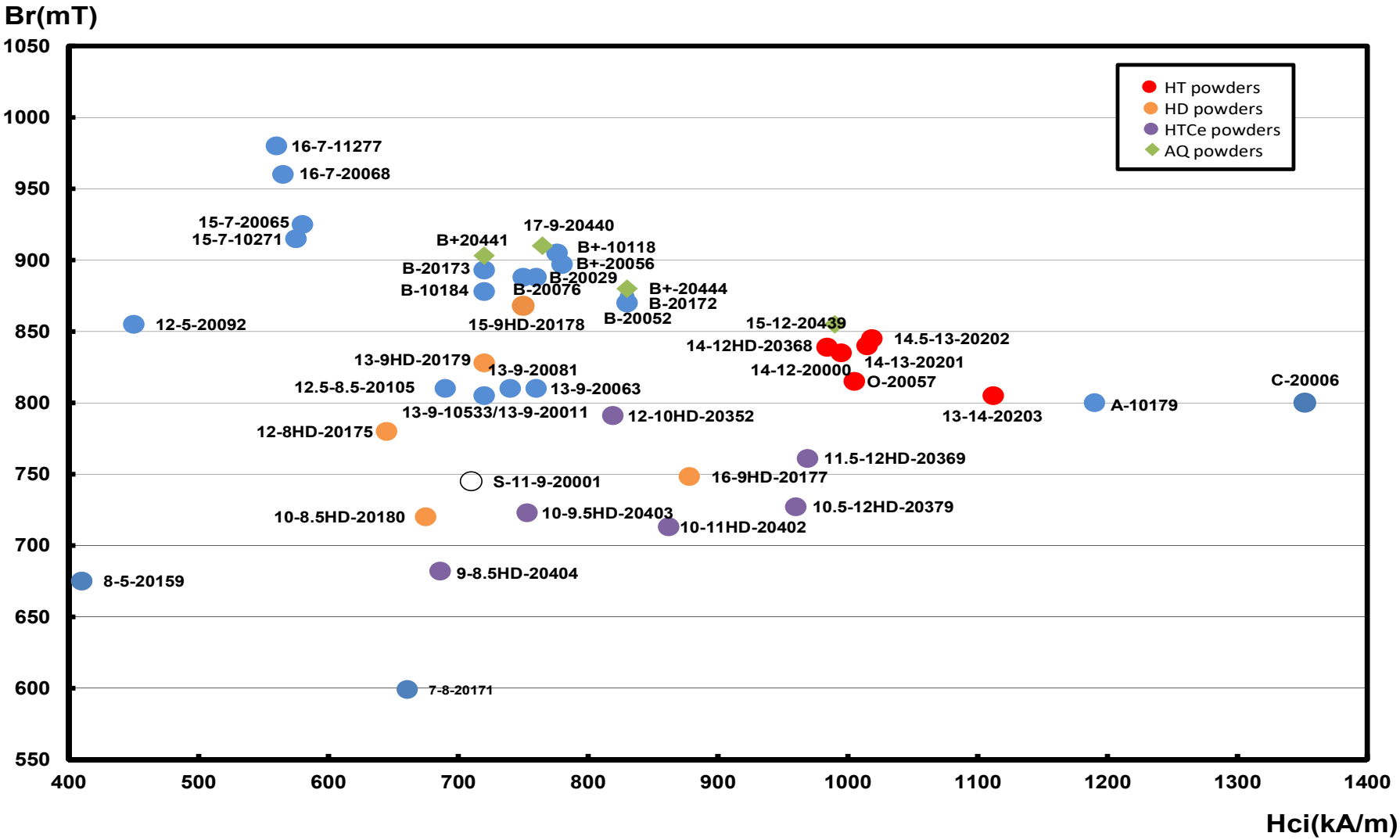


Magnequench business by application

Recent Developments in Material

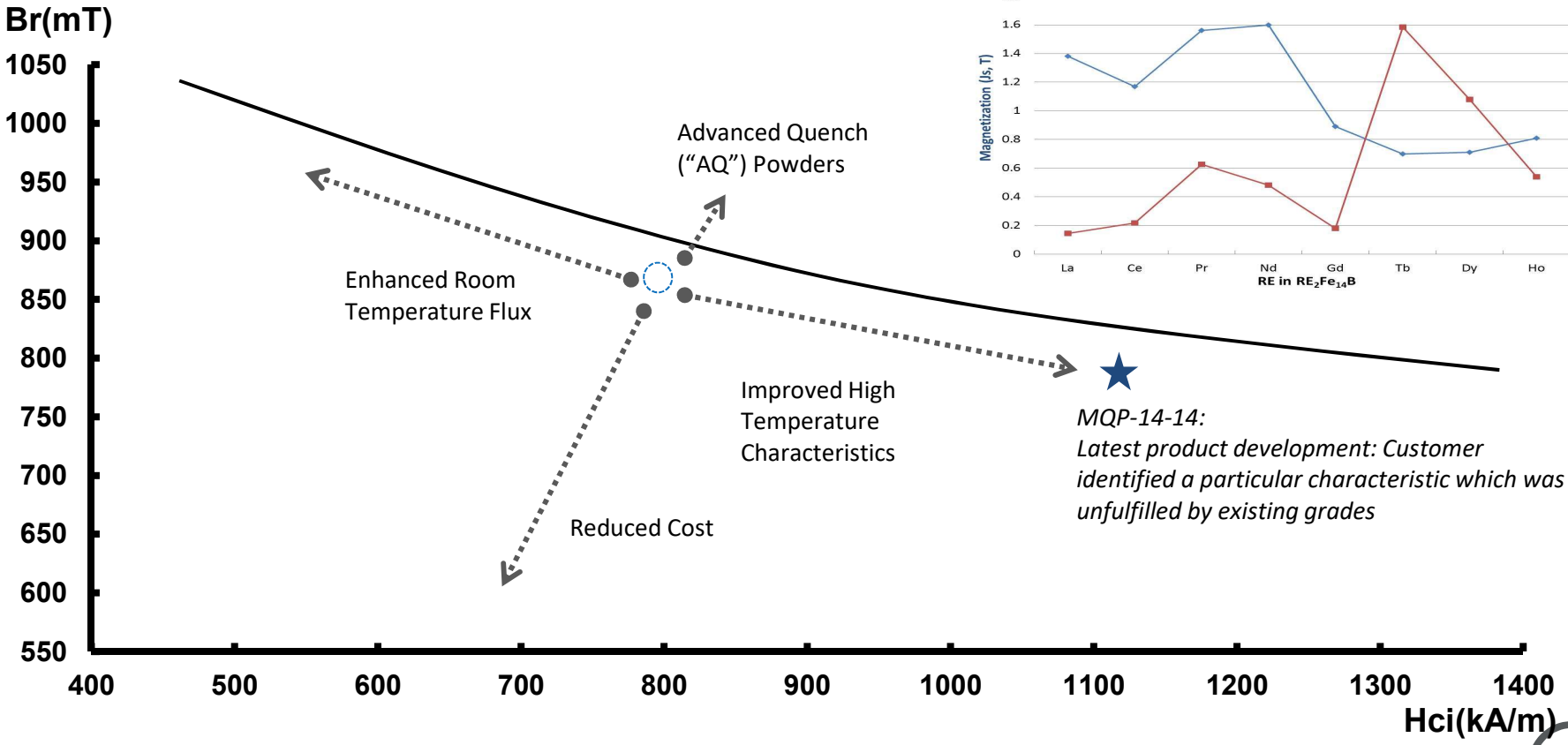
Advanced Quenching (AQ-Powders)

Powders for Bonded NdFeB magnets (MQP™)

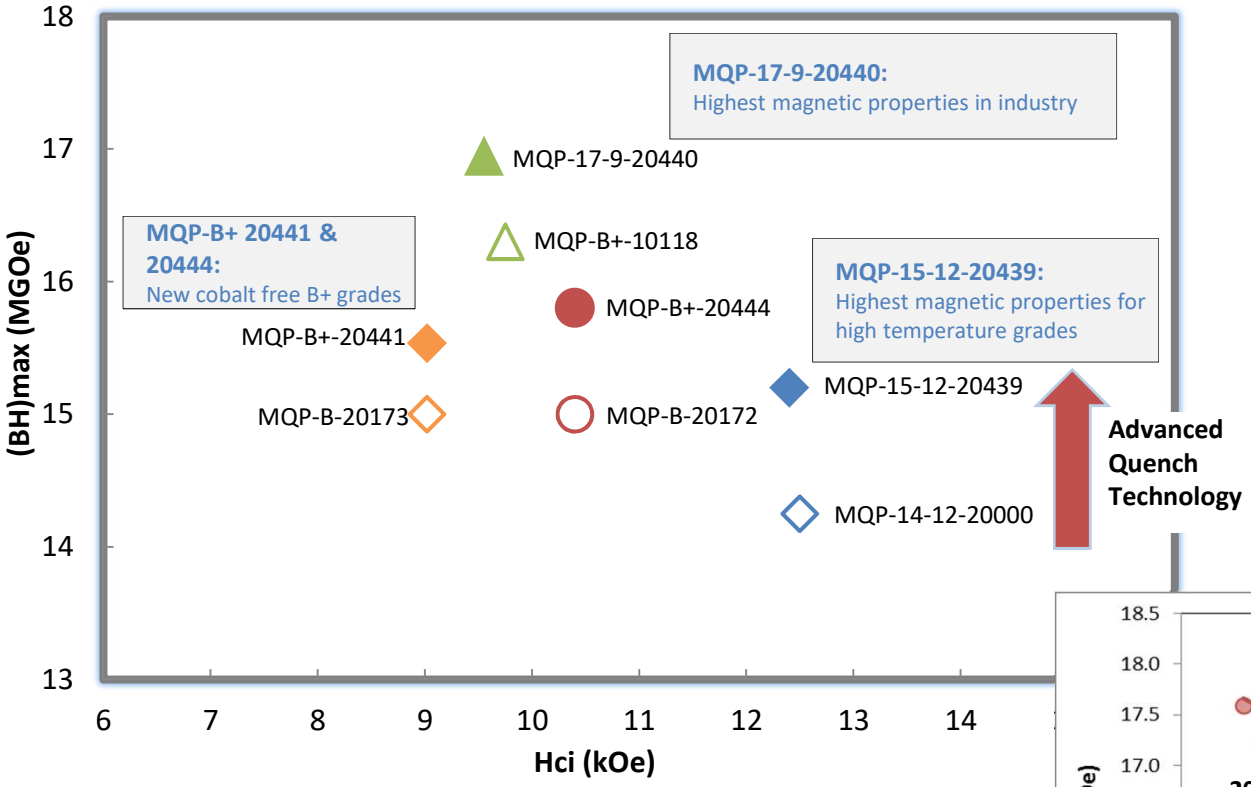


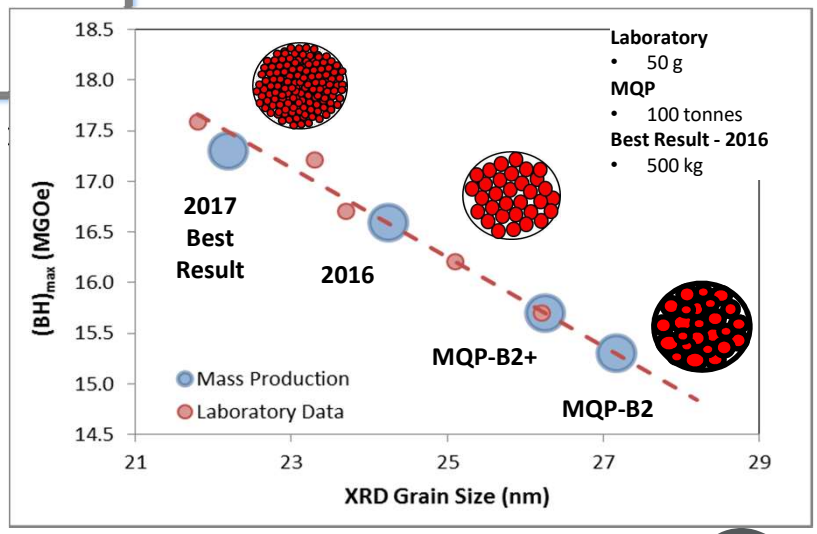
Tailored MQP™ Magnetic Materials

- We enhance our product portfolio by relentlessly analyzing and implementing methods to achieve the maximum performance of jet cast MQP™
  - We develop tailored materials quickly and easily



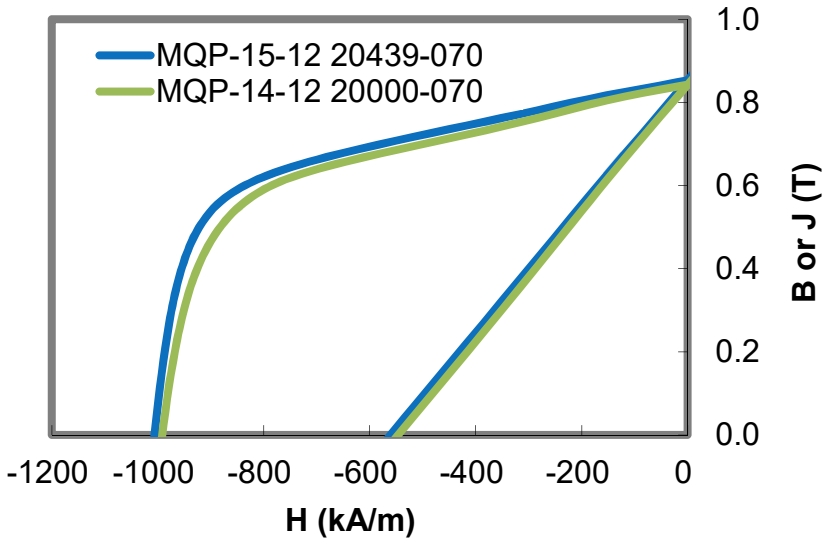
Advanced Quenching ("AQ") Technology





MQP™-15-12-20439: Improved Magnet for High Temperature Applications

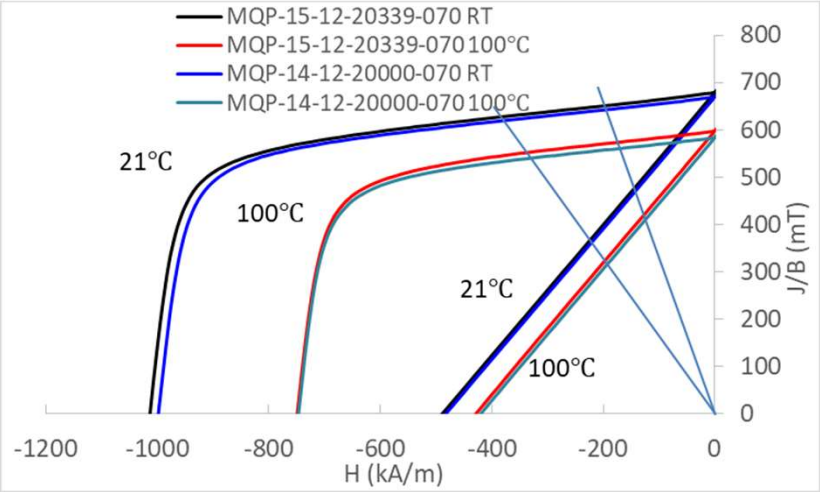
- 20 mT improvement in B_r and 8 kJ/m^3 improvement in $(BH)_{max}$
- Provide more working flux in automotive applications currently using 14-12

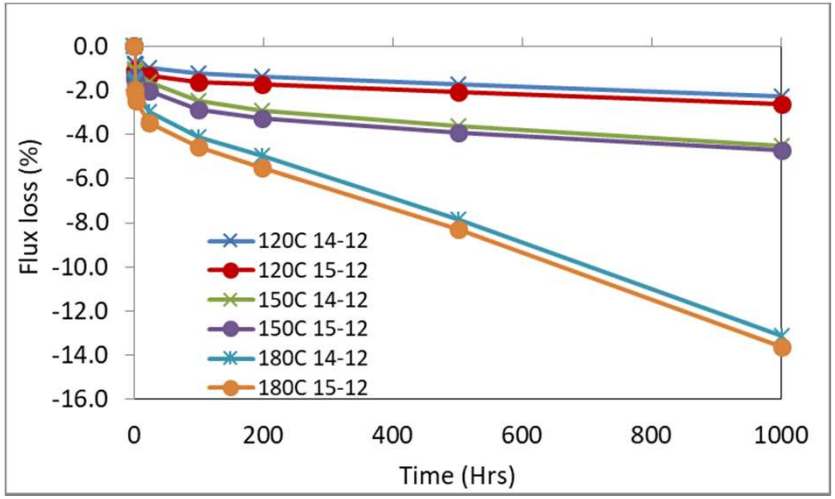


	Powder Properties			Magnet Properties (OD9.8mm X H6.5mm)				
	B_r (kGs)	$(BH)_{max}$ (MGOe)	H_{ci} (kOe)	Density (g/cm^3)	B_r (kGs)	$(BH)_{max}$ (MGOe)	H_{ci} (kOe)	B_r (kGs)
MQP-15-12- 20439	8.50 - 8.60	14.8 -15.6	11.9 – 12.9	5.981	6.86	5.87	12.17	10.12
MQP-14-12- 20000	8.20 – 8.50	13.4 -15.1	11.8 – 13.2	5.984	6.78	5.82	11.98	9.87

*Aging data forthcoming. Estimated to be similar to MQP-14-12-20000

Magnet from AQ based Powder: Magnetic and Thermal Aging Properties



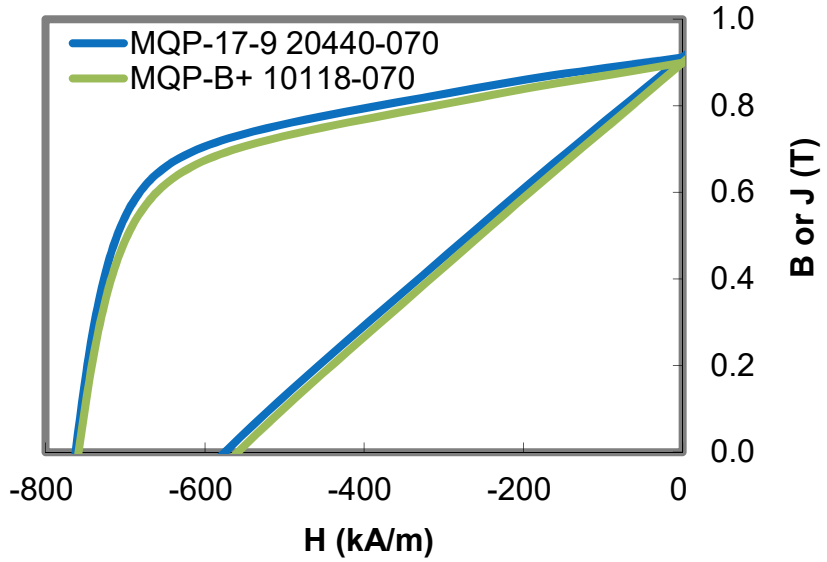


Magnet	B_r (kGs)	H_c (kOe)	H_{ci} (kOe)	$(BH)_{max}$ (MGOe)
MQP-15-12	6.86	5.87	12.17	10.12
MQP-14-12	6.78	5.82	11.98	9.87

- 1.2% Increase in B_r
  - Considering the non-linear magnetic circuit and saturation in the magnetic circuit the maximum airgap flux increase will be less than 1.2%
- Same aging performance

MQP™-17-9-20440: Highest magnetic properties in industry

- B_r and BH_{max} even higher than MQP™-B+-10118
- Stretches today's boundaries of performance of MQP™ grades



Material	Powder Properties		
	B_r (kGs)	$(BH)_{max}$ (MGOe)	H_{ci} (kOe)
MQP-17-9-20440	9.05 – 9.15	16.6 -17.3	9.4 – 9.7
MQP-B+-10118	8.95 – 9.05	15.8 – 16.6	9.3 – 9.8

Magnet Properties (OD9.8mm X H6.5mm)				
Density (g/cm^3)	B_r (kGs)	$(BH)_{max}$ (MGOe)	H_{ci} (kOe)	B_r (kGs)
6.011	7.27	6.01	9.35	10.93
5.993	7.19	5.94	9.36	10.72

*Aging data forthcoming. Estimated to be similar to MQP-B+-10118

Recent Developments in Material

Low Cost and High Temperature Cerium Powders

High Temperature Cerium Grades

- Magenquench introduced a new series of “High Temperature” grades
  - Providing aging characteristics that allow the magnets to operate at higher temperatures – as required for many automotive applications –
  - Leveraging cerium, the most abundant (and thus lowest cost) rare earth

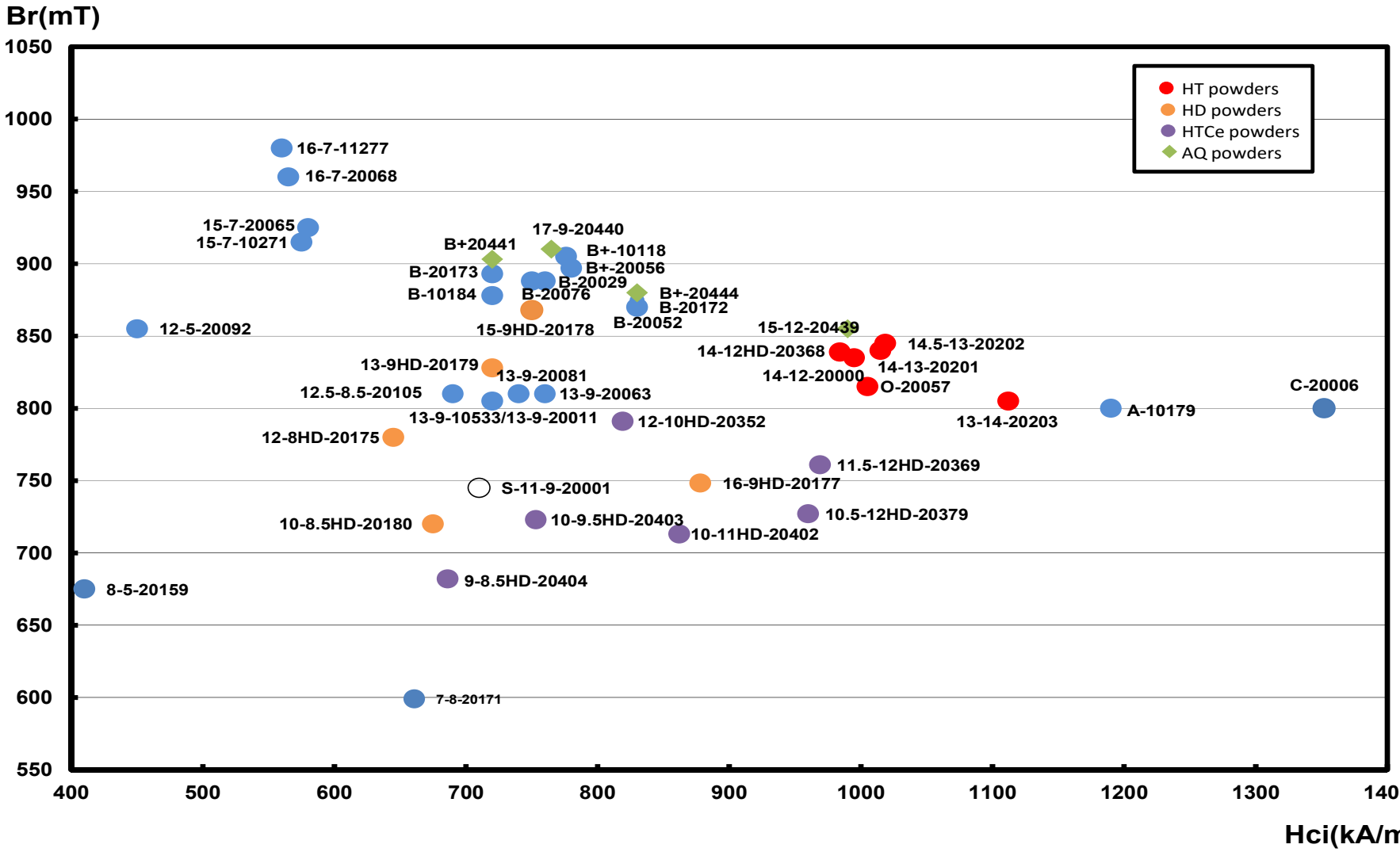
- The powders’ magnetic and mechanical characteristics are fully **customizable** according to specific customer or application requirement

High Temperature Cerium Grades

- This presentation describes generally powder magnetic performance and magnet aging (%) at:
  - 150°C
  - 120°C

- As the content of Ce changes, both the magnetic performance and the magnet aging characteristics change
  - The changes which are a function of the material and the process are well understood
  - This enables us to produce a specific, bespoke which would be tailored to the customer's requirement

Range of isotropic materials for Bonded NdFeB Magnets



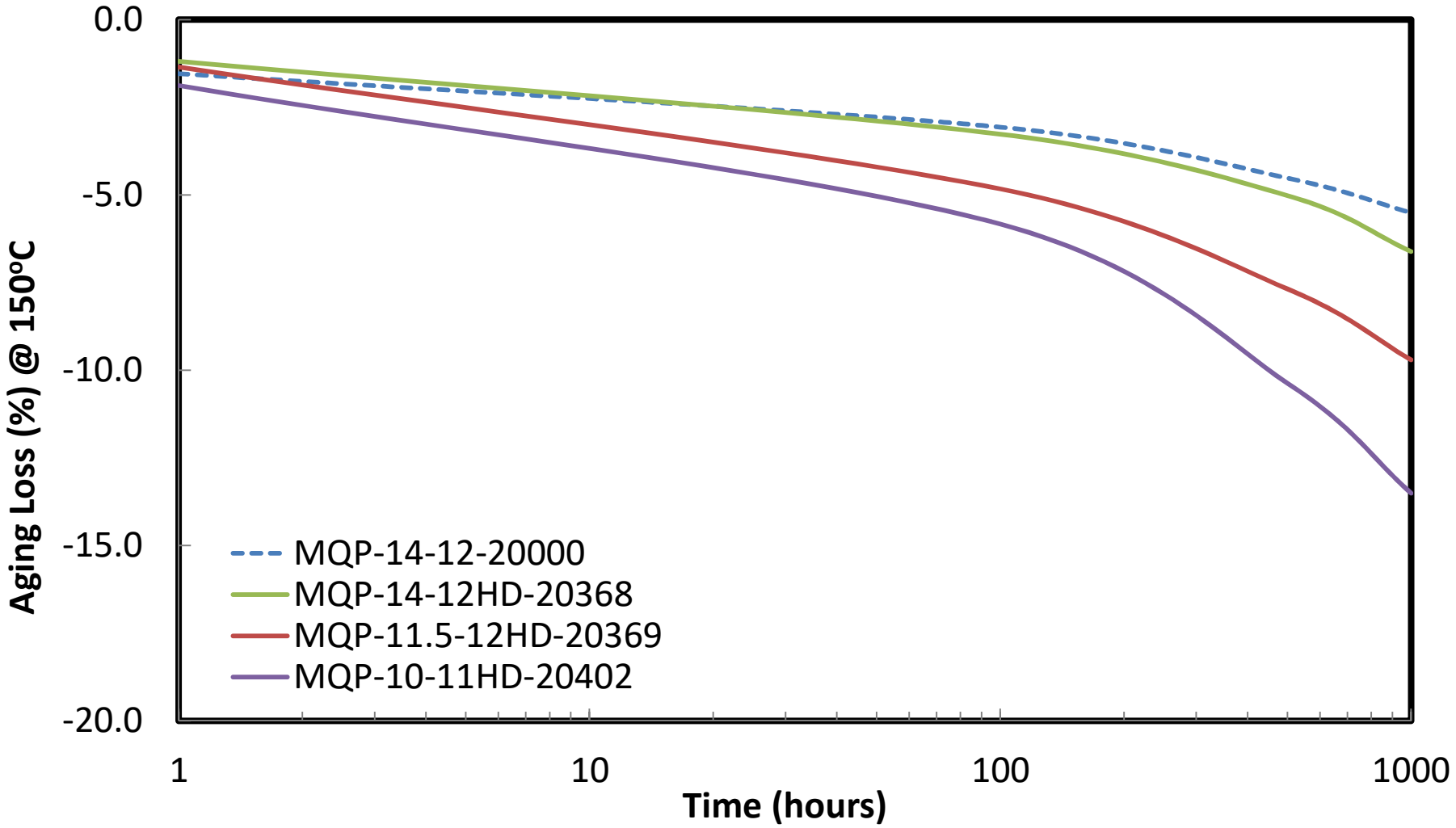
For thermal stability up to 150°C

Category	Product Name	Ce/La (%)	Powder			PC2 Magnet
			Br (kG)	Hci (kOe)	(BH)max (MGOe)	Aging (%) @ 1000hr 150°C
14 MGOe	MQP-14-12	-	8.50	12.3	14.5	-5.4
	MQP-14-12HD-20368	-	8.39	12.4	14.3	-6.6
<14 MGOe	MQP-11.5-12HD-20369	Ce30	7.61	12.2	11.7	-9.7
	MQP-10-11HD-20402	Ce50	7.13	10.8	10.2	-13.5

Magnequench can customize the powders according to your requirements within the range as shown above up to 50% Cerium; magnetic and aging values are preliminary.

As a simple rule:
A substitution of 50% Nd by Ce reduces Br by about 15%.
A substitution of 50% Nd by Ce reduces Hci by about 10%.

For thermal stability up to 150°C



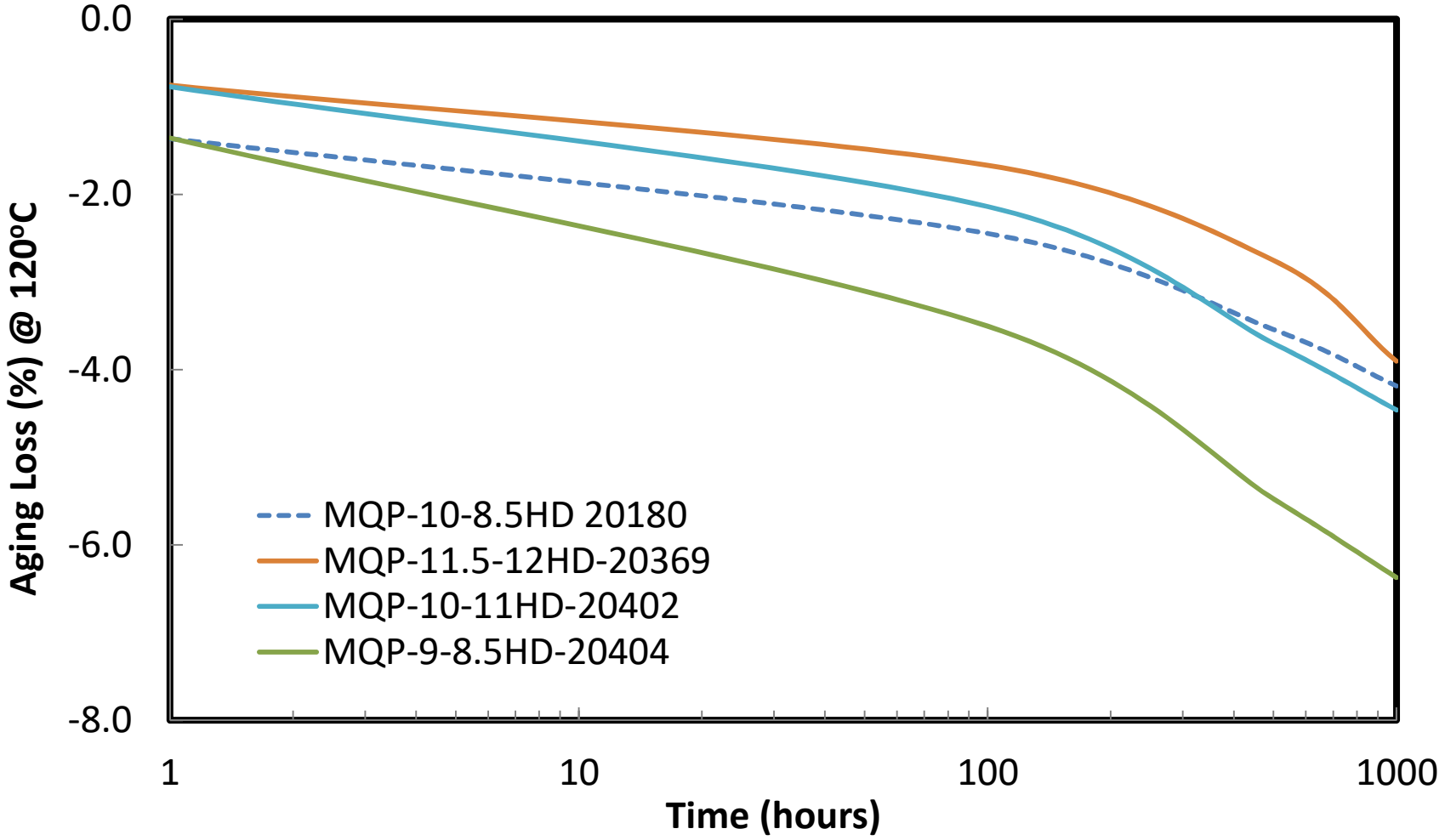
For thermal stability up to 120°C

Product Name	Ce/La (%)	Powder			PC2 Magnet
		Br (kG)	Hci (kOe)	(BH)max (MGOe)	Aging (%) @ 1000hr 120°C
MQP-10-8.5HD 20180*	Ce60	7.22	8.6	10.3	-4.2
MQP-11.5-12HD-20369	Ce30	7.61	12.2	11.7	-3.9
MQP-10-11HD-20402	Ce50	7.13	10.8	10.2	-4.5
MQP-9-8.5HD-20404	Ce70	6.82	8.6	9.0	-6.4

*Existing grade for comparison

Magnequench can customize the powders according to your requirements within the range as shown above up to 70% Cerium; magnetic and aging values are preliminary.

For thermal stability up to 120°C



Magnequench

Magnequench update

17. May 2018

Thank you!

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