evs 27
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ArcelorMittal

Effect of punching and stress concentrations on mechanical behaviour of electrical steels

Dennis Van Hoecke, Sigrid Jacobs, Lode Vandenbossche, Bastien Weber, Emmanuel Attrazic

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In collaboration with
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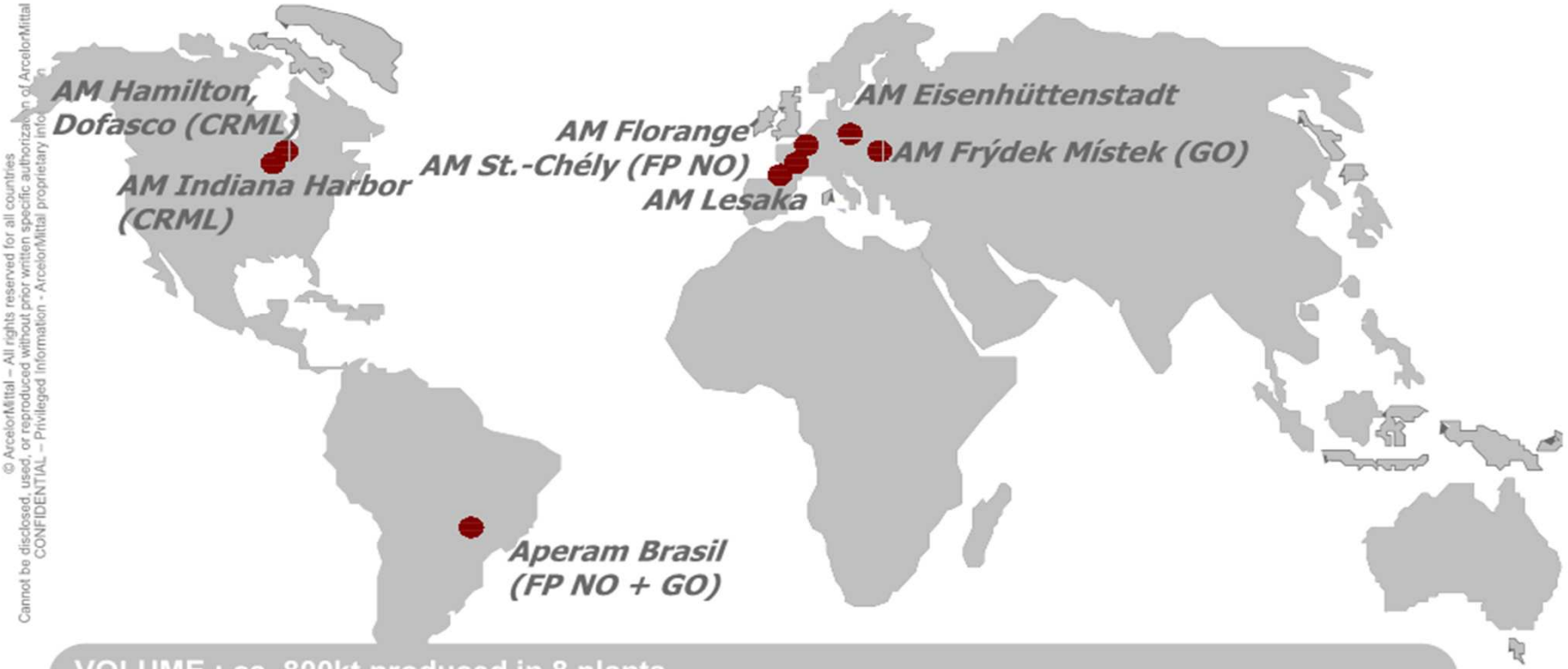
Presentation Outline

- ArcelorMittal electrical steels
  - General info
  - Grades for automotive applications
- Advanced mechanical data
  - Temperature effect
  - Fatigue

Notes:

- ArcelorMittal is a key supplier for large high efficiency machines for power generation, rail traction, industrial motors
- We supply customers worldwide, also because we follow our global customers in all their production sites

Electrical steel
Production sites



VOLUME : ca. 800kt produced in 8 plants

A WIDE RANGE of GRAIN ORIENTED as well as NON ORIENTED ELECTRICAL STEELS

Complemented with FeNi and FeCo alloys (produced in France)

DEDICATED COMMERCIAL and TECHNICAL ASSISTANCE TEAM

… But base frequency for industry is 50/60Hz and much higher for automotive.

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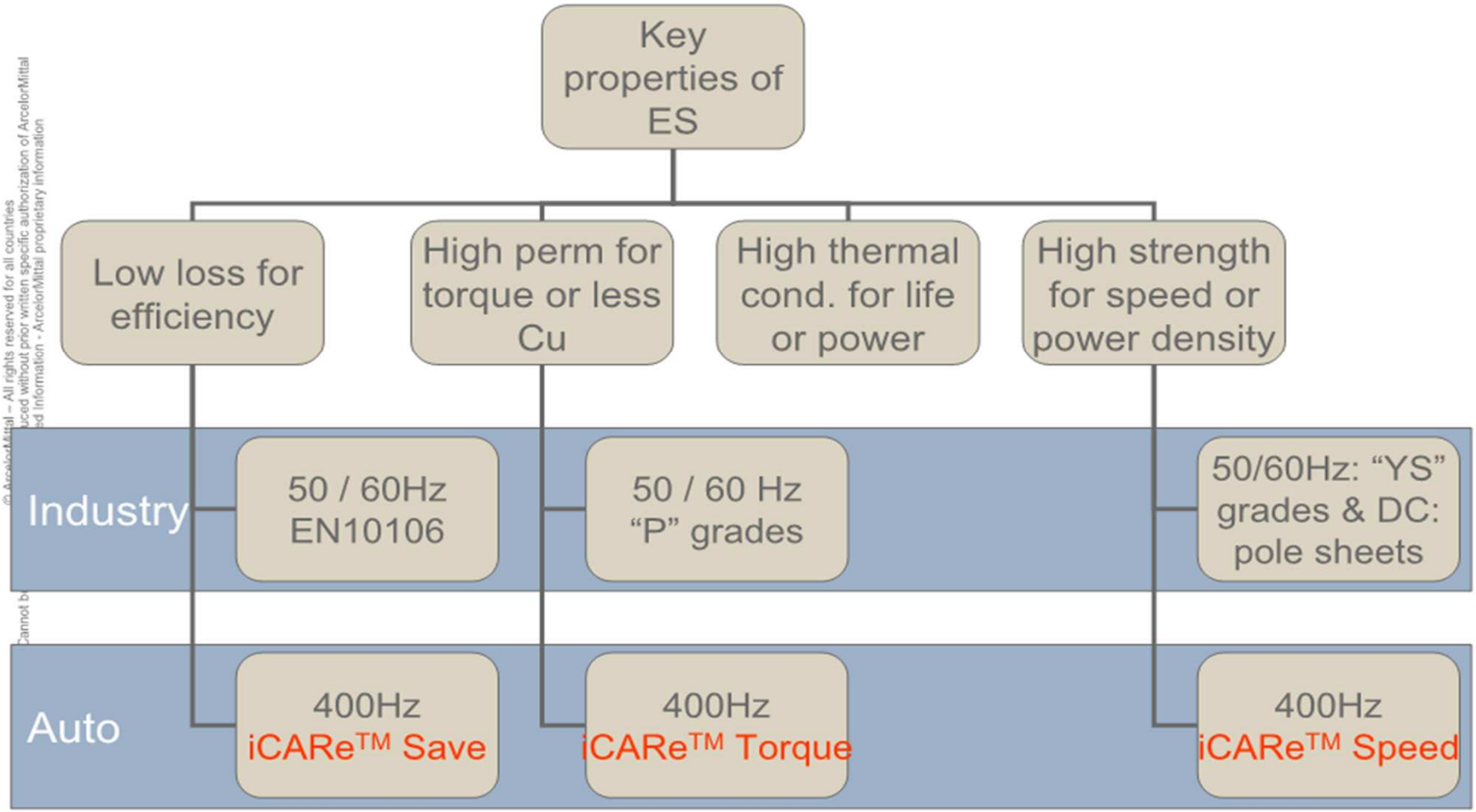

iCARe™

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Save is steel with very low losses, to save weight, to save energy, to improve efficiency.

Save is in particular useful for stators of high frequency machines.

Save 20-13 or Save 20-15
Save 25-14 or Save 25-16
Save 27-15 or Save 27-17
Save 30-15 or Save 30-17

Torque is steel with high permeability, to improve air-gap flux, to obtain high motor torque or to generate high current.

A stator using **Torque** improves the motor's brake-away torque.

Torque 20-15
Torque 25-16
Torque 27-16
Torque 30-17 or Torque 30-18

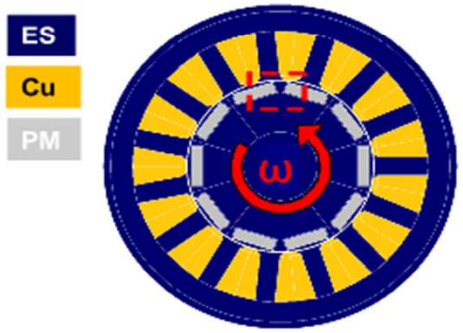
Speed steel has high strength for high speed rotors which maintain high levels of magnetic performance.

These grades allow the machine to be more compact and have a higher power density.

Speed 35-440
or Speed 35-510

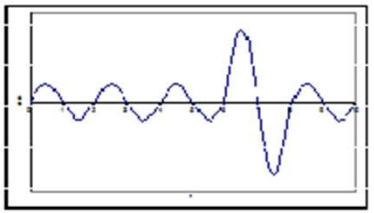
Mechanical design of electrical motors

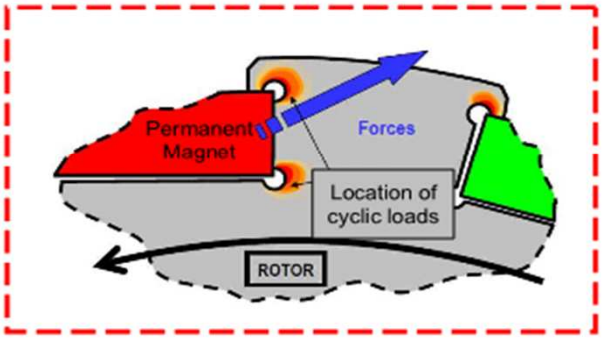
- Little data available in literature for electrical steels (ES) and the influence of service factors (temperature, notches, etc.)
- Due to lack of data, mechanical motor designers rely on general design rules for “steels”
- Are these general design rules for steel applicable for ES?



$\omega \rightarrow F_{centrifugal}$

$\Delta\omega \rightarrow \Delta F_{centrifugal}$

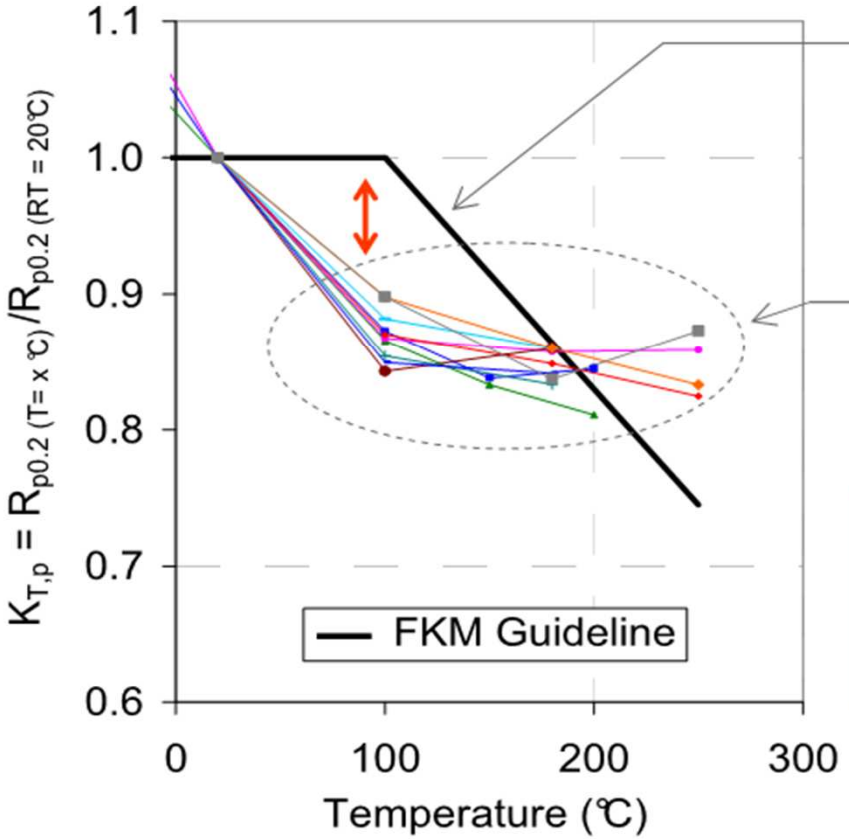




Electrical steel vs. “normal” steel

- With respect to traditional structural steels, non-oriented electrical steels for traction motors are:
  - Supplied in low thicknesses: typically 0.3 to 0.5 mm (vs. 0.7 to 4 mm for traditional steel)
  - Generally designed to optimise electromagnetic performance
    - Ferritic microstructure
    - Elevated Si content (1.3 to 3.2 wt%)
    - Higher average grain size (30 – 160 µm)
- Effect on mechanical properties investigated experimentally, e.g.
  - Static behaviour at elevated temperature
  - Dynamic behaviour near notches

Example 1: Effect of temperature on yield strength (YS), for cases with ω = constant



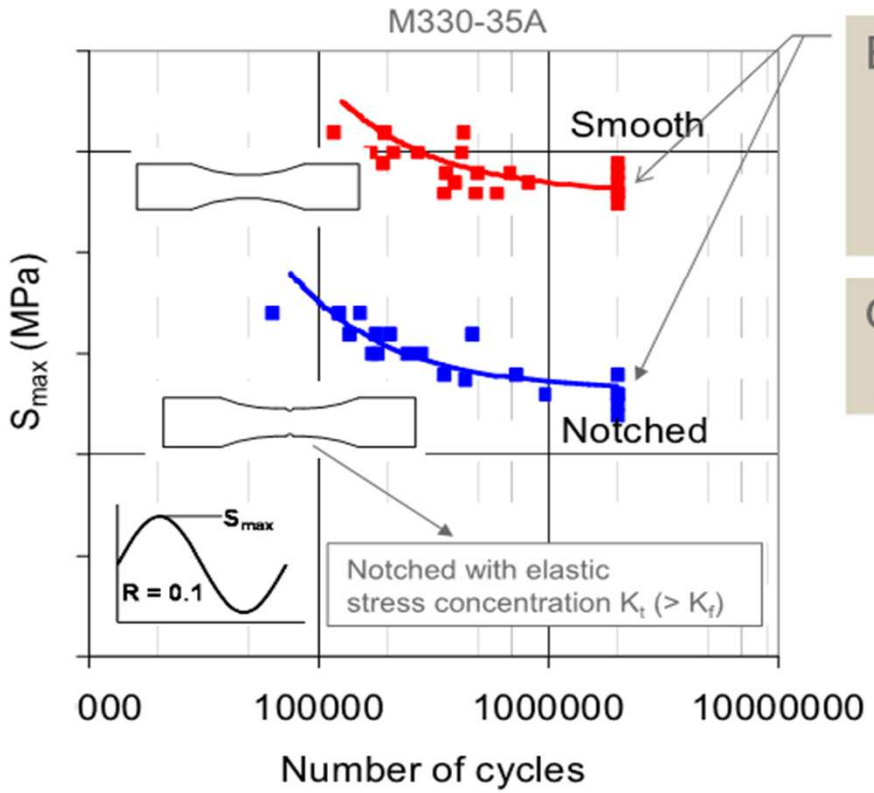
$$\frac{YS_{\text{elevated temperature}}}{YS_{\text{room temperature}}}$$

according to guideline

Experimentally determined

Guideline underestimates the drop in yield strength below 200°C (up to 15%)

Example 2: Effect of notches on fatigue strength – relevant for cases with Δω



Experimental result:

$$K_f = \frac{\text{Fatigue limit without notch}}{\text{Fatigue limit with notch}} \approx 1.7$$

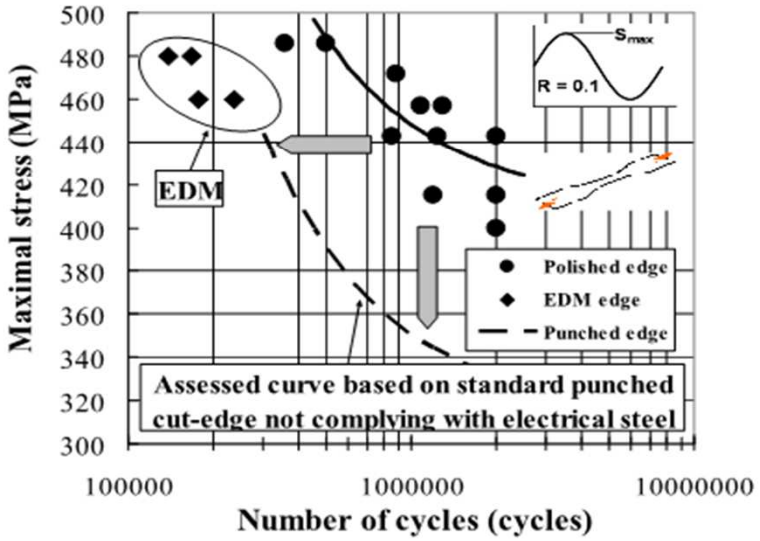
Guideline (based on K_t, R_m):

$K_f = 1.9$

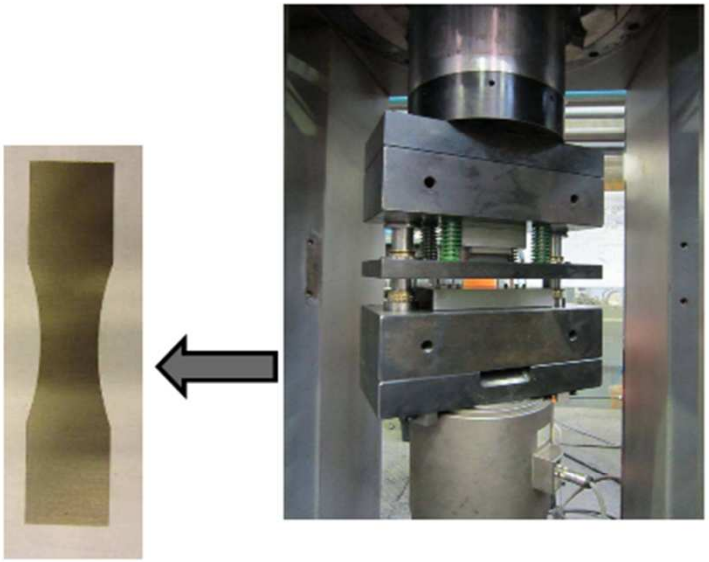
Guideline slightly underestimates the drop in fatigue strength due to a notch for this ES

Example 3: Effect of punching on fatigue strength – relevant for cases with Δω

- Estimate

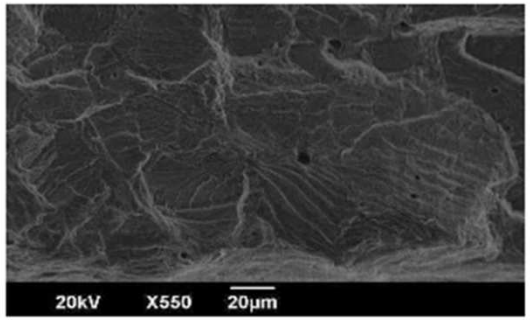


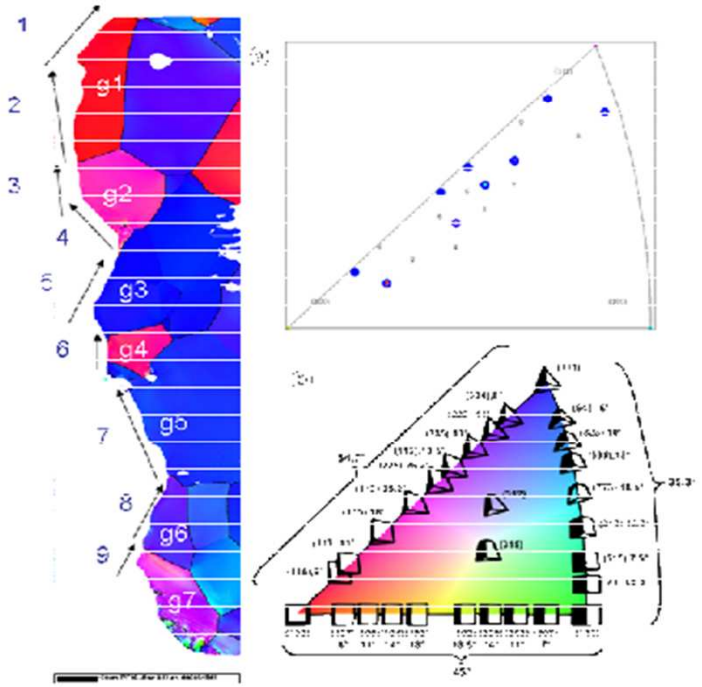
- Punching tool for fatigue samples



Should a failure still occur: Post analysis support

- Fatigue failures (analysed laboratory fatigue samples)
  - In general: of cleavage transgranular type
  - Global propagation direction perpendicular to loading direction: crystallographic orientation less relevant
  - Inside the grains the crack seem to propagate along {110} planes
  - Possibility of metallurgical “twinning” phenomenon and its effects is under investigation





Conclusions

- ArcelorMittal, as electrical steel producer, is offering to help the electrical traction machine designer to meet the tough challenge of defining maximal power density output electrical machines.
- iCAReTM ES steel grades for automotive
  - magnetically very soft types for the stator: Save for compact high efficiency and Torque for machines with high mechanical output
  - mechanically very hard types for the rotor called Speed.
- Electrical motor designers often rely on general design rules for steels to dimension their mechanical designs.
- General design rules do not always correctly reflect the actual behaviour (e.g. yield strength as a function of temperature).
- Advanced technical data are needed to dimension the mechanical design more accurately and increase power to weight ratio, efficiency, …
- ArcelorMittal can provide key customers with these advanced mechanical data and also help them with the post analysis of failures if needed.

Thank you for your attention !

www.arcelormittal.com/industry/electricalsteels