Niobium in automotive exhaust systems

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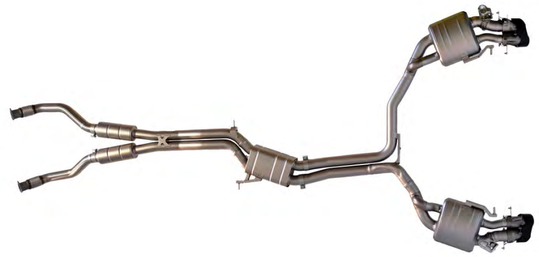
Contents

- Development of modern exhaust systems
- New ferritic steels
- Niobium’s benefits
- Niobium in action

Development

- Exhaust systems changed significantly in recent years
- Driven by factors including
  - Tougher emissions legislation
  - Costs
  - Requirement to improve operating life
- Materials must combine
  - High corrosion resistance
  - Ability to withstand high operating temperatures
  - Ease of manufacturing
  - Cost efficiency



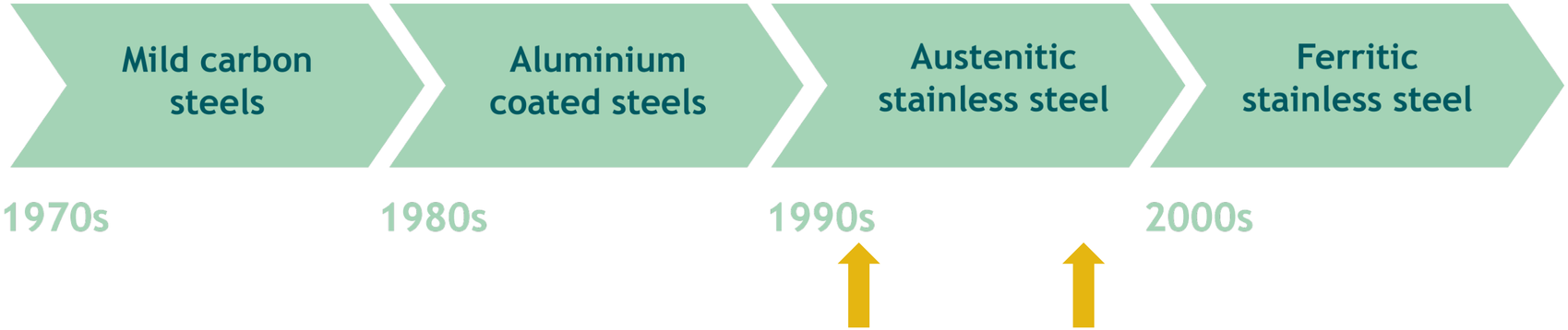
Evolving materials mix

Technical issues

Poor corrosion resistance
- Salt
- Exhaust condensate

Changing technology
- Higher operating temperatures (emissions regulation)
- Need to improve corrosion resistance further

New emission control systems
- Increased exhaust temperatures further
- Urea corrodes many commonly used stainless steels in high temperatures



Introduction of emissions regulation

Resulted in
- Requirement for regeneration and engine downsizing
- Requirement for leak-free assembly, installation and operation for the full useful life of the vehicle
- Greater strength and durability requirements

Commodity Super Cycle

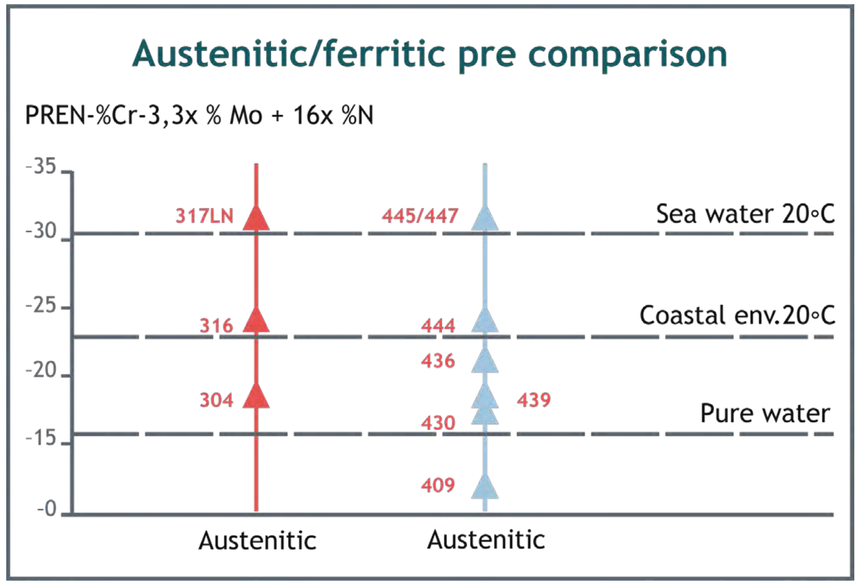
Resulted in
- Significantly increased prices for key alloys such as nickel
- R&D launched to find new materials

External issues

Source: CBMM

Ferritic steels

- Historically ferritic steels seen as inferior to austenitic steels
  - Particularly with regards to corrosion resistance
- New grades of ferritic steels developed after significant R&D
- Comparable corrosion resistance to austenitic grade in specific environments with enhanced
  - Thermal characteristics – low expansion, high temperature oxidation resistance, conductivity
  - Creep resistance
  - Workability – easier to cut and reduced tool wear, reduced springback
  - Higher yield strength
- No nickel content



PRE measures corrosion resistance of a stainless steel grade in a chloride-containing environment. For every austenitic grade there is a ferritic grade with comparable corrosion resistance.

Source: The Ferritic Solution, ISSF 2007

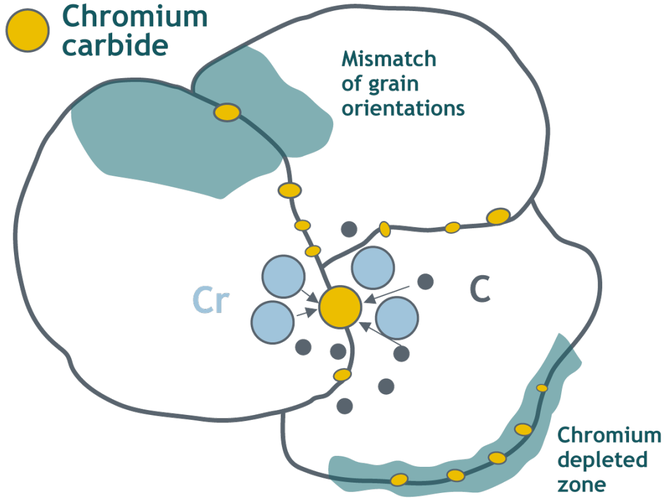
Niobium alloyed Ferritic steels

- Niobium microalloying has made a significant contribution to development of improved ferritic steels
  - Acts as both a stabilising agent and as a strengthening agent
- Niobium's performance benefits include
  - Increased corrosion resistance
  - Better high temperature properties
  - Improved drawability and formability
  - Enhanced weldability
  - Higher production efficiency

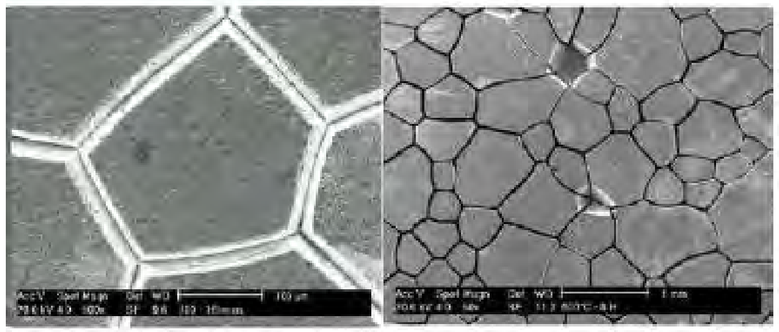
Better corrosion resistance

- Chromium is the source of stainless steel's corrosion and oxidation resistance
- At high temperatures chromium can combine with carbon to create chromium carbide – this process is called sensitization
- Areas with depleted chromium are prone to corrosion which can cause the failure of components
- Niobium prevents formation of chromium carbides by reacting with the carbon and ensuring chromium is not consumed

Figure 2: Chromium depletion at the grain boundaries or sensitization



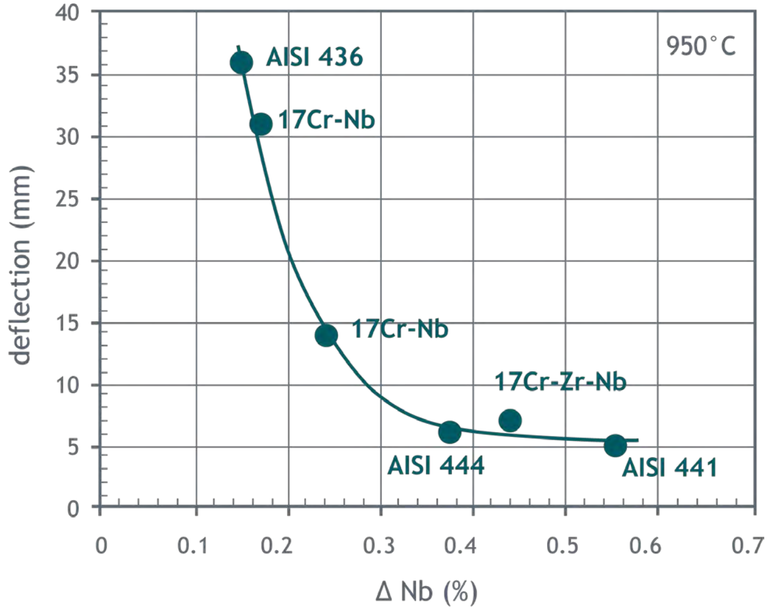
Source: http://www.ssina.com/corrosion/igc.html



Source: Serna-Giraldo, C.A. (2006)

Higher operating temperatures - Creep resistance

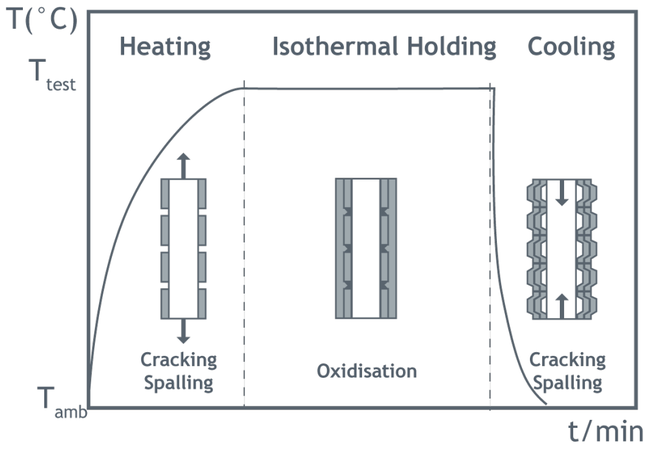
- Creep deformation occurs due to extended operation at high temperatures
- Niobium increases creep resistance by
  - Stabilising the steel microstructure
  - Controlling formation, dissolution and coarsening of precipitates
- Therefore, Niobium helps to extend the lifetime of exhaust parts by reducing deflection (deformation) over time

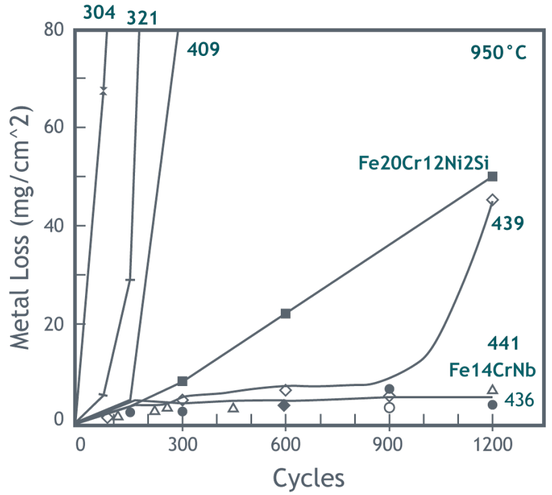


Source: Schimitt et al (2005)

Higher operating temperatures - Cyclic oxidation

- Repeated cycles of heating and cooling can cause exhaust parts to crack and break apart (spalling) due to different rates of thermal expansion
- Cracking of the part's outer oxide layer causes corrosion
- Niobium creates more adherent and less porous oxide that protects the metal from oxygen exposure



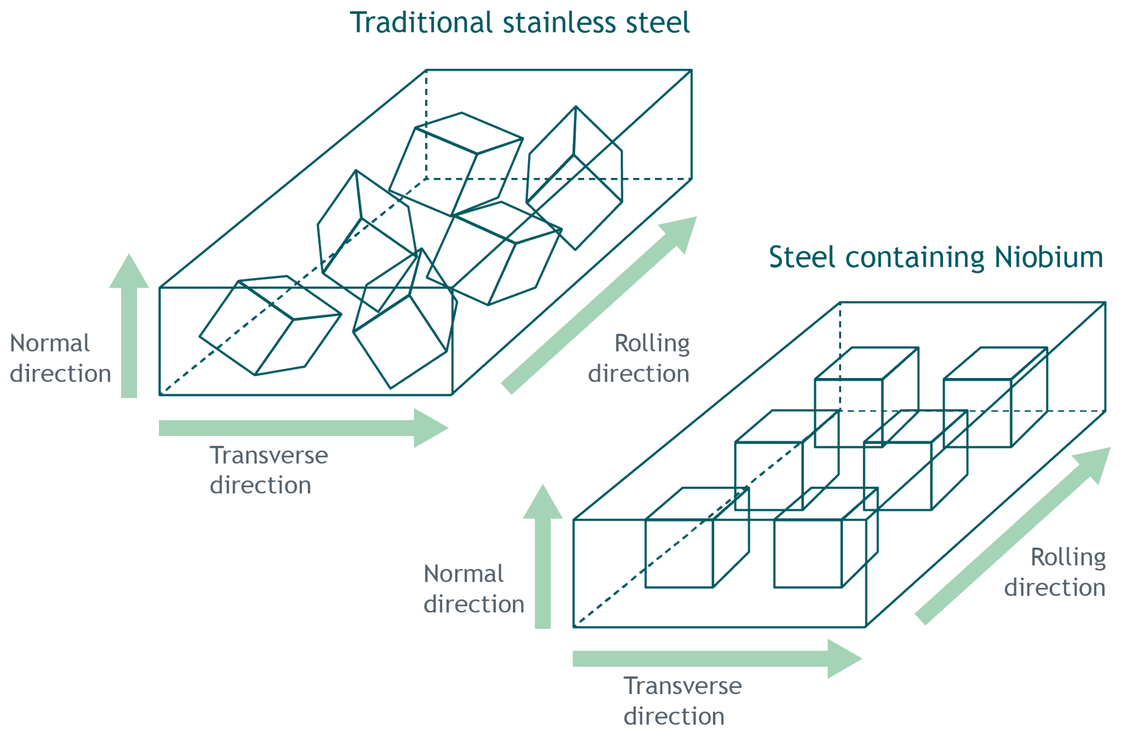


Source: Schimitt et al (2005)

Drawability and formability

- The complex design of many exhaust parts means it is important for materials to be easily workable
- Niobium alloying improves the microstructure of steels to create a more homogenous material with better aligned grains
  - Improved robustness and ductility
  - Increased strength & toughness
  - Better surface quality
- Improved drawability and formability can create production efficiencies and enable optimal part design

Illustration of grain alignment in steel



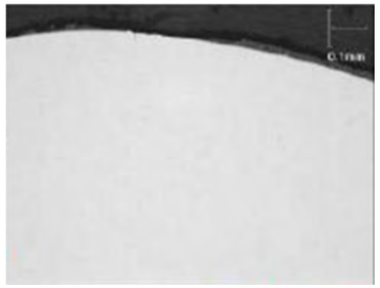
Source: http://www.dierk-raabe.com/textures-of-steels/

Weldability

- Welding creates heat affected zones around the weld
- In some steels this can result in sensitization occurring
- Niobium prevents sensitization occurring thus ensuring continued corrosion resistance

	Filler wire composition	3rd level bead composition (27V ; Ar + 3% O_2)	
430LNb	C= 0,024% N= 0,019% **Nb- 0,308%**	C= 0,024% N= 0,018% **Nb- 0,272%**	→ Transfer ratio : 88%
430Ti	C= 0,068% N= 0,017% **Ti- 0,332%**	C= 0,064% N= 0,017% **Ti- 0,148%**	→ Transfer ratio : 45%

Top of the 3rd layer
after IG corrosion test (with bending)



430Ti

Non-stabilised structure > IG corrosion

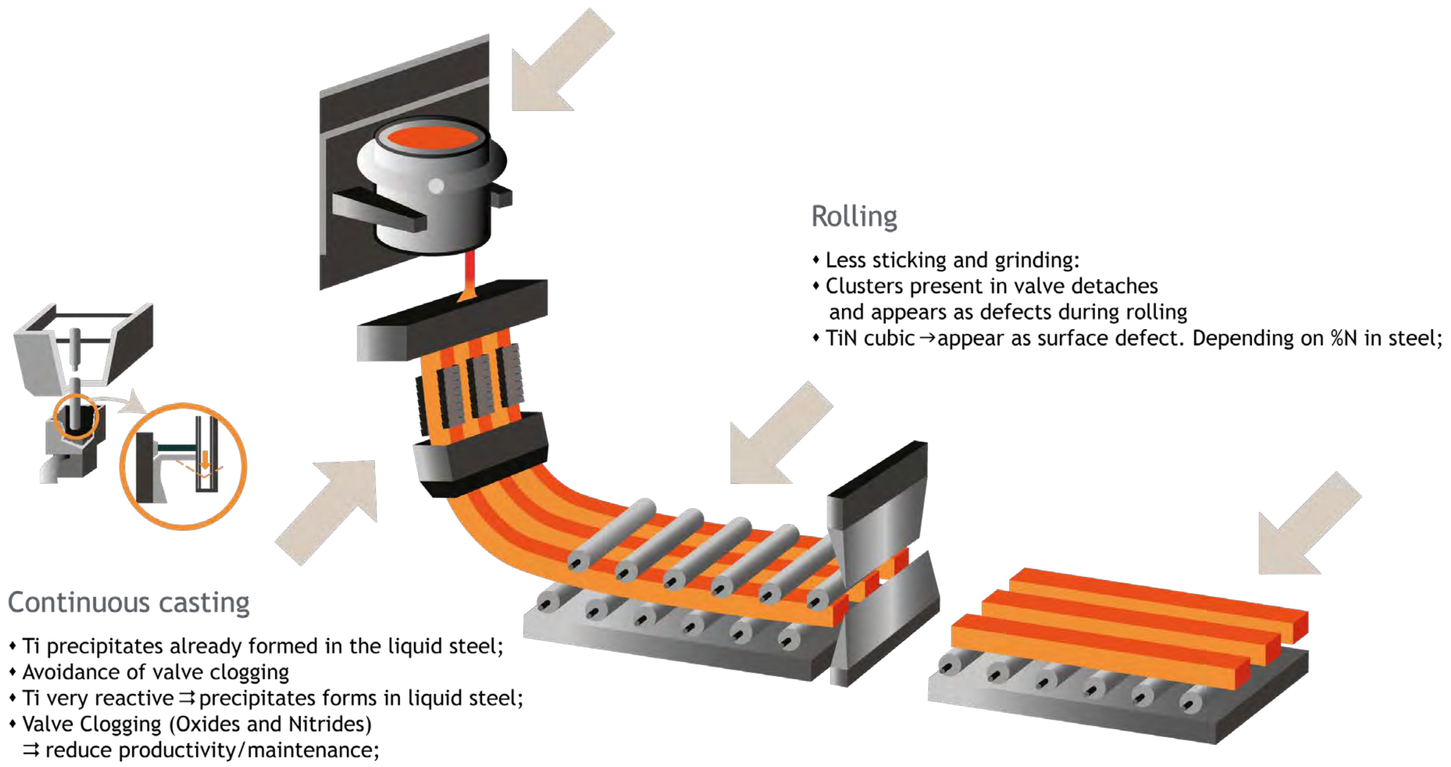
430LNb

Stabilised structure > no IG corrosion

Source: UGITECH Exhaust F1™(430LNb)

Improved production efficiency

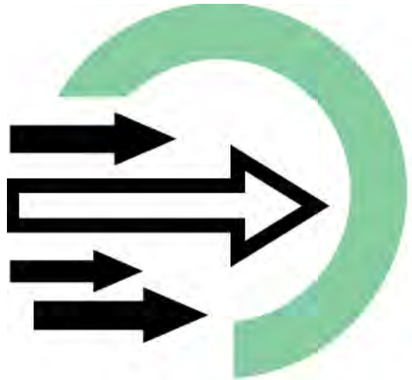
- Niobium contributes to improved efficiency in
  - Melting
  - Casting and
  - Rolling
- By mitigating issues caused by other alloying elements



Source: CBMM

Benefits of Niobium in practice

- 409 grade steel is one of most commonly used in exhaust applications
- Very limited corrosion resistance (11%Cr) and generally no Niobium
- Failures common in welded areas
- 409 Nb – Ti alternative (0.15-0.31%)
  - 40% higher corrosion resistance (Mazda B Method)
  - Better performance at higher temperatures (up to 650C)
- Cost effective compared to higher Chrome alloys



Better Performance

Increased Value