Modern Bainitic Steels for Automotive Applications

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with the inputs from RFCS DUCTAFORM Project

Why developing Advanced High Strength Steels (AHSS) for automotive sector?

- Two major & contradictory drivers for the use of newer steels in the automotive industry
  - **Fuel efficiency / CO₂ emission reduction**
    - Steep increase in the pressure on OEM to comply with new regional regulations
    - Function of weight of steel parts, controlled by gauge and design
  - **Increase or maintain at least safety performances**
    - Determined by the energy absorbing capacity (strength and residual ductility after forming) or anti-intrusion capacity (strength)

→ but, need to preserve the feasibility of the parts (formability)
Hopefully, steel manufacturing offers a large range of opportunities (achievable tensile properties).
Variety of achievable tensile properties thanks to specific microstructure designs

- **Bainite** appears as a key component in most of industrial products for automotive sector to tune tensile strength / elongation balances of steels
  - either thanks to the introduction of bainite as a component in multi-phase steels (FB, DP, TRIP)
  - or as main phase (CP)

- Properties of steels with bainitic matrix can be also tune playing with various strengthening mechanisms
  - Lath size
  - Dislocation density
  - Precipitation
  - Martensite volume fraction
But others properties are essential for car makers

- Ductility of cut-edges (stretch-flangeability)

- Fatigue (often related to UTS)

- Welding (about 3000 spot welds in a car) → related to chemical composition

Wheel closure made of HR DP600 (VeraStyle® brevetée par Hayes Lemmerz International)

S. Sadagopan, D. Urban, 
Bainite can help to optimize these key IUP (often related to sensitivity to damaging mechanisms)

- From DP to fully bainitic
  - UEI decreases & HE increases (for a given strength level)
  - Related to a decrease in the hardness contrast between phases
Certain parts & designs need more!

- Highly microalloyed FB enables to reach new « strength-formability » compromise for HR products
  - Recent but commercial grades now by AM (CP800) and some competitors (Nanohiten JFE/TKS)
Thus, “modern” bainitic in steels are nowadays widely used by carmakers

- Partially bainitic (FB, CP800, CP1000) or fully bainitic steels (M800) are now commercial products for automotive making
  - Chassis applications (mainly HR) thanks to high YS and high HE
  - Anti-intrusion part in BIWS (CR/HR) thanks to high YS
Carbide-free bainitic steels can be an alternative option for the development of both HR and CR solutions

- Also called TRIP with bainitic matrix, TBF (Kobe), SB-TRIP (Posco)

- Main interests
  - Can be declined in HR and CR products
  - Permitted to reach high strengths (no soft phases), high elongation (TRIP effect) and high resistance to damage (lath structures, reduced hardness contrast)

- Recent participation of AM to a RFCS project (finished last year) led by CENIM dedicated partially to the development of this metallurgy for CR and annealed products for automotive application

NB: Nano-Bainitic steels correspond to the same concept pushed to the limits in term of carbon content

J.C. Hell et al.

0.3C2.5Mn1.5Si0.8Cr - Bainite transformation
Ms+50 °C
YS = 780 MPa, UTS = 1400 MPa, UE% = 14%, E = 20%
DUCTAFORM: examples of studied chemical compositions

- In the frame of the DUCTAFORM project, choice of chemical composition made by numerical alloy design (adaptation of hardenability and T0’ line criterion playing with Mn and Cr level)
  - Mn substitution by Cu/Ni to avoid band structure and for recycling issues
- Expectations from literature:
  - The higher C and gammagene elements the higher the tensile performance
- Some examples of studied compositions:

<table>
<thead>
<tr>
<th>Heat</th>
<th>Composition</th>
<th>C</th>
<th>M</th>
<th>Si</th>
<th>Cr</th>
<th>Cu</th>
<th>Ni</th>
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DUCTAFORM: Optimization of bainitic transformation

- Bainitic transformation conditions have been optimized (temperature and durations) to reach stasis
- BHD > actual industrial capability except for alloy CR5
- Expected microstructures reached
  - No polygonal ferrite
  - Various morphology of Bainite and MA components

<table>
<thead>
<tr>
<th>Alloys</th>
<th>Soaking Temperature (°C)</th>
<th>Soaking Duration (s)</th>
<th>BHT (°C)</th>
<th>BHD (min)</th>
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Data and micrographs from CENIM
### DUCTAFORM: Mechanical properties (tensile, HE and Bending)

<table>
<thead>
<tr>
<th>Alloys</th>
<th>BHT (°C)</th>
<th>YS (MPa)</th>
<th>UTS (MPa)</th>
<th>Uel (%)</th>
<th>TEI (%)</th>
<th>RA (%)</th>
<th>HE (%)</th>
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> 1000 MPa  > 11 %  > 30 %
DUCTAFORM: Optimization of properties
– Effect of bainitic holding temperature

- Confirmation that tensile properties of CFB can be tuned thanks to BHT
  - Change in work-hardening mechanisms as a function of microstructure
    - 400°C: 79% bainite / 14% RA / 7% M → TRIP effect
    - 300°C 79% bainite + TM / 9% RA / 12% M → composite effect
    - 350°C: 84% bainite + TM / 8% RA / 8% M → composite effect
  - Evolution in lath morphology and thickness / misorientation profile

Data and micrographs from CENIM

TRIP effect

« DP » effect
DUCTAFORM: Strength / Formability performances vs. traditional VHSS
Active international competition in this particular field

- Very active research field in both industrial and university laboratories
  - Major steelmakers as Kobe steel, Voestalpine, Thyssen-Krupps or Arcelormittal involved (Patent activities and corporate communication)
  - The first derived products are almost available in the market (TBF 1470 / TBF 980 from Kobe)

- Numerous academic teams
  - Cambridge University – England
  - Postech – Corea
  - CENIM-CSIC – Spain
  - Shinshu University – Japan
  - LEM3 Metz university – France
  - Mc Master University – Canada
  - Deakin university – Australia
  - …
Conclusions and perspectives

- « Modern » bainitic steels are already and massively used in automotive sector (chassis and BIWS application)
  - Steelmakers has developed new generation of microalloyed bainitic steels (already commercial) to improve the HE/formability performances

- Carbide-free bainitic steels appears to be another potential solutions for HR and CR products
  - Two RFCS projects led by CENIM-CSIC with the collaboration of AM has permitted to confirm the interest of such metallurgy for automotive applications
  - Permitting to improve simultaneously formability, strength and sensitivity to damaging mechanisms (toughness, HE, …) compared to traditional VHSS

- All the details will be issued in the final DUCTAFORM report (available soon in EU bookshop)