Modern High Strength Steels

Modern high strength QT, TM and Duplex-stainless steels

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Summary

• Definition of Modern High Strength steels
• Main mechanical properties (tensile-Charpy)
• Examples of use of modern steels
• Forming conditions
• Weldability aspects
• Post Weld Heat Treatment
• Conclusion
TMCP steel definition

• TMCP = Thermomechanically Controlled Process. Also known as TM or TMP steels.

• They are hot-rolled steels made using controlled heating and rolling temperatures and controlled cooling rates to produce microstructures not reproducible by heating and cooling alone.

• Microalloying and thermomechanical rolling below the austenite recrystallisation temperature produces fine-grained, dislocated austenite with a high density of ferrite nucleation sites.

• Free cooling in air (thinner plate) or accelerated controlled water cooling produces fine-grained microstructures (F+B+P).

• Low carbon and impurity contents combine with the fine grain size to give excellent combinations of strength, toughness and weldability.
Quenched and Tempered steel definition

• QT steels are low Carbon (lower than for N steel of same strength level), low alloyed (Mn, B, Cr, Mo, Ni, ...), high purity

• Oil, spray or water quenching gives a fine grain bainitic to martensitic hard microstructure (ferritic for N steels)

• Tempering makes the microstructure softer, tougher and improves the homogeneity of mechanical properties over the thickness

• Tempered martensite gives the best compromise for strength and toughness

• Yield/Strength ratio is of 0.8 (upper bainite) to 0.95 (martensite) compared to about 0.6/0.7 for ferrite

• Good weldability is achieved with low carbon and high purity
Duplex stainless steel definition

- Duplex microstructure consists approximately equal amount of ferrite and austenite in solution annealed condition, which contributes to their high strength and ductility
- Yield/Tensile strength ratio is 0.7
- High contents of alloying elements Cr, Mo and Ni imply good resistance to localised and uniform corrosion
- Good weldability, can be welded using most of the welding methods used for austenitic stainless steel
- Produced in a full range of product forms; plate, coil, sheet, tube, fittings, welding consumables etc. Hot rolled plate is dominating product form in thickness range 5 to 100 mm
<table>
<thead>
<tr>
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<th>Min.YS MPa</th>
<th>Min.Rm MPa</th>
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<tr>
<td></td>
<td>275</td>
<td>355</td>
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<tr>
<td>Part 3 - N</td>
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<td>490</td>
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<tr>
<td>Part 5 - TM</td>
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<td>Part 6 - QT</td>
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<td>Min.Rm MPa</td>
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## Charpy V properties of HSS

### EN 10028 Charpy V requirements at T/4 transverse specimens

<table>
<thead>
<tr>
<th>Test Temp. °C</th>
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<th>- 50</th>
<th>- 40</th>
<th>- 20</th>
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<tr>
<td>Part 3 - N</td>
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<td>NL1 27J</td>
<td>N,NH 30J</td>
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<tr>
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<td>ML1 27J</td>
<td>M 27J</td>
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<tr>
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<td>QL1 27J</td>
<td>Q,QH 27J</td>
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<td></td>
<td>+ 20</td>
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<tr>
<td>Austenitic</td>
<td>60 J</td>
<td>60 J</td>
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<tr>
<td>Duplex</td>
<td>40 J</td>
<td>60 J</td>
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</tr>
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</table>
Examples of TMCP steel applications-1

• Used where high strength and improved weldability can be applied with advantage:

• Linepipe for gas and oil transport. Commonly yield strength classes from 420 - 490 MPa. YS 555 MPa has also been used and YS 690 MPa has been developed.

• Offshore structures YS classes 355, 420, 460 MPa.
Examples of TMCP steel applications -2

- Bridges YS classes 420, 460 MPa
- Shipbuilding (icebreakers) YS 500 MPa
- Lifting equipment YS 700 MPa
- Tanks and pressure vessels YS 420 & 460 MPa
Examples of QT steel applications -1

- P355Q is used in place to P355N for pressure vessels to improve the weldability - PWHT
- P500Q is preferred to P355N or Q for weight saving for PV on off-shore platforms (separators and scrubbers,…) - PWHT; however, application fields are limited due to non-experience and missing rules for application
- P690Q is used for the racks of jack-up platforms (thickness up to 300mm) – no PWHT; large application field are also bridge building, earth moving machines and crane construction. PE applications is extremely seldom
Examples of QT steel applications -2

• Higher grades (up to 960 Mpa YS) are used in welded constructions without pressure (cranes, bridges, vehicles..) or for pressure service (penstocks for hydraulic power plants, hull of submarines..) – no PWHT

• Some conventional QT steels (thick plates or forgings) are used from 40 years for thick pressure vessels: MnNiMo steels for PV of nuclear power plants in accordance with Nuclear Codes, CrMo(V) steels for large PV for oil refineries in accordance with ASME Code. PWHT
Examples of Duplex S steel applications -1

• Duplex SS were broadly introduced for pressure vessel applications in late 1970s, due to their strength and better stress corrosion cracking resistance than austenitic SS
• Twice as high proof strength vs. austenitic SS ⇒ considerable wall thickness reduction
• Less Ni than austenitic grades ⇒ reduced cost
• Most common duplex grade for pressure vessels is 22.5.3/EN 1.4462/2205, 22% Cr, 5-6% Ni, 3% Mo and 0.17% N (YS 460 MPa)
Examples of Duplex S steel applications -2

- The applications cover a variety of industries such as pulp and paper; sulphite digesters, oxygen reactors etc., and different types of reactors in chemical industries, and high pressure components in desalination plants.
Forming conditions of TMCP steel

- Due to their low carbon and impurity contents, TMCP steels are well suited to cold forming even to large strains.
- Due to their lower carbon contents, straining raises the transition temperature of TMCP steels less than that of equivalent N steels.
- The low transition temperatures of TMCP steels mean that they can have good toughness even after large amounts of straining and subsequent ageing.
- The increase of strength and transition temperature caused by warm forming is less for TMCP steel than for N steel. 550 - 600°C is the best range.
- Hot working is not allowed.
Forming conditions of QT steel

• **Cold forming** is the general practice when possible with the available power of the forming equipment

• **Strain ageing effect** (+10 to +20°C on FATT) is equal or lower than on Normalised steels

• **Semi-hot forming** as to be limited to the tempering temperature –25°C for QT steels and to AC1-50°C for N steels

• **Hot forming** needs a regeneration heat treatment after forming: normalising for N steels and quenching and tempering for QT steels
Forming conditions of Duplex SS

- DSS have good formability in cold condition in a variety of fabrications such as rolling of cylindrical sections, press forming and vessel and head forming
- High strength and work hardening ⇒ Sufficient power of forming equipment
- Responding to forming similarly to austenitic SS at twice the thickness (roughly)
- Heat treatment is required when deformation is higher than 5%, similarly to ferritic steels
- Hot forming is normally performed at 1000-1100°C, depending of grade, and should be followed by a quench annealing
Weldability of TMCP steel

For a given yield strength, the CEV of TMCP steel is about 0.06 units lower than for N steel.

– preheat can be eliminated (saving e.g. 50 €/t)
– less need for PWHT due to better FL/HAZ toughness
– less repair welding
– less documentation
– weldability of 500 MPa TMCP as good as 355 MPa N
Weldability of QT steel

• For a same grade, the Carbon Equivalent of QT is lower than for N steels; ex. P355N CE=0.42, P355Q CE=0.39

• As a consequence, cold cracking sensitivity is reduced, HAZ hardness is lower and HAZ toughness higher

• When carbide forming elements are high (Cr, Mo, V, Nb) these steels may be susceptible to reheat cracking during PWHT, so a limitation of these elements and of impurities is necessary

• The control of mismatch needs to optimise the selection of welding consumables
Weldability of Duplex S steel

- Duplex SS generally have good weldability and can be welded using most of the welding methods used for austenitic SS (SMAW, SAW GTAW etc.)
- The material should be welded without preheating
- The material should be allowed to cool between passes, preferably to below 150°C
- To obtain good weld metal properties in as welded condition, filler material shall be used
- The arc energy should be kept within certain limits to achieve a good balance between ferrite and austenite in the weld.
PWHT of TMCP steel

• PWHT will not normally be required for TMCP applications in PVs (t < 30 mm)

• When PWHT is required, data should be requested from the steelmaker for the steel concerned.

• Normally, temperatures up to 600°C will only have small effects on the tensile and toughness properties of the base plate and welds.
• PWHT is required by the Codes above certain limits of thickness (30 mm) and/or cold forming deformation (2%, 5%)
• Also for QT steels, PWHT conditions (temperature, time, TP) have to be limited in regard of tempering conditions to avoid a softening of the base material
• Toughness modifications of HAZ, base and weld metal have to be considered for each type of steel
• For the reduction of residual stresses, the PWHT conditions are different for each steel type in dependence of their chemical composition
• Outside of PE-industry, a lot of applications of QT steels are in as welded condition
• Post-weld stress relief is normally not recommended for duplex SS
• Post-weld heat treatment should normally be full solution annealing followed by water quenching
Conclusions

• Modern HSS are largely used for high safety constructions but not so much for pressure equipment

• ECOPRESS work has characterized as well steels authorised for EN 13445 (P500Q,CrNiMoN22.5.3) as steels not yet authorised (P420M,P690Q)

• Specific investigations concerning the main effect on the materials’ properties of cold forming, welding and PWHT have been performed

• In dependence of the ECOPRESS results, recommendations on a better coordination of the standards of materials and of the PED will be proposed in order to reduce the conservatism due to the old experience with traditional steels with much lower Y/T ratios