RECENT DEVELOPMENTS IN THE USE OF QUENCHED AND SELF-TEMPERED HOT ROLLED H-BEAMS

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Abstract

The quenching and self-tempering (QST) installation at the ArcelorMittal heavy sections rolling mill of Differdange (Luxembourg), developed in collaboration with the Centre de Recherches Métallurgiques (CRM) in Liège (Belgium), is in industrial operation since more than 20 years. The possibility of combining high strength with outstanding welding properties, besides a high ductility and good through-thickness properties, made heavy 'jumbo sections' in QST steels an immediate success in specific construction applications.

QST steels are considered conventional structural steels and are known in the market as HISTAR (High-Strength-ArcelorMittal) grades. They are covered by EN and ASTM standards. Eurocode 3 (EN 1993) also takes into consideration these new high strength steels by proposing specific design parameters and buckling curves.

Sections made of QST steel have become an integral part of sophisticated applications such as the American 'strong column-weak beam' concept for high-rise structures in seismic areas as well as for members of offshore structures.

Latest research projects cover topics such as the behaviour of high strength QST steels during galvanisation and the improvement of weld design parameters. Research has also been performed on asymmetrically fabricated castellated beams (ArcelorMittal Cellular Beams) where QST steels are used especially in the parts where their full strength can be activated as well as high performance composite structures combining H-beams in QST grades with high strength concrete.

This paper summarises the latest developments in research projects aimed at optimising design parameters and the improvement of the efficiency in new applications of QST beams.

Keywords: QST steel, castellated beams, seismic, offshore structures

1. DESCRIPTION OF THE QST PROCESS

The conventional method for producing high-strength steels consists in adding alloying elements to the steel and rolling at controlled temperatures. This thermomechanical (TM) rolling technique is however limited by:

- The mechanical power of the rolling mills as this process asks for high deformation rates at relatively low temperatures,
- The impossibility of substantially reducing the carbon equivalent (CE) value of the steel and, as a consequence, of improving its weldability.

The QST process uses water and the rolling heat as working substances, see Figure 1. After the last pass of a TM rolling, an intense water-cooling is applied to the whole surface of the beam. Cooling is interrupted before the core is affected and the outer layers are tempered by the flow of heat from the core to the surface.
At the exit of the finishing stand, directly at the entry of the cooling bank, the rolling temperature of the beam lies typically at 850°C. After the quenching over the whole surface of the section, self-tempering is achieved at 600°C.

2. PROPERTIES OF QST STEEL

The QST process considerably increases the yield strength and the toughness of the steel. Due to much lower carbon equivalent values when compared with conventional structural steel grades, the weldability and the ductility of the steel grades are significantly improved.

2.1 Mechanical properties

All HISTAR grades offer improved guaranteed minimum value for yield strength over the whole range of product thicknesses. A comparison between the yield strength of HISTAR grades and conventional thermomechanically rolled fine grain grades in accordance with EN 10025-4:2004.

2.2 Weldability

Figure 2 summarizes the relationship between chemical composition, product thickness and yield strength for the conventional rolling processes and the QST process. In Europe, the grades HISTAR 355 to 460 have a maximum CE value of 0.43 %.

\[
CEV[\%] = C + \frac{Mn}{9} + \frac{(Cr + Mo + V)}{8} + \frac{(Cu + Ni)}{15}
\]

In the range of normal heat inputs during welding (10-60 kJ/cm) and provided that low hydrogen filler metal and auxiliary products are used, a preheating is not necessary for temperatures of the structure over 0°C.
2.3 Toughness

Nowadays, it is well established that a certain level of toughness of the steel is required in order to avoid propagation of cracks associated with brittle fracture in the base material during welding or during seismic loading from earthquakes.

3. HISTAR IN SEISMIC AREAS

3.1 Toughness requirements

In the USA, after the Northridge earthquake in California, the task group revising the existing standards on earthquake design recommends for base metal minimum toughness requirements of 20J at +21°C for enclosed structures and 20J at +4°C for exposed structures. This is the reason why QST grade 65 /ASTM A913 (= HISTAR 460) is the only steel with a yield higher than 345 MPa (= grade 50 /ASTM A913) that can be used in California for the columns of moment resisting frames.

3.2 Structural concept

QST grade 65 /ASTM A913 (= HISTAR 460) is used in order to achieve the ‘strong column – weak beam’ concept, which is nowadays the most economical way in Northern America to design framed structures of high-rise buildings in seismic zones.

3.3 Reduced beam Section

A further improvement of the moment frame connections is the reduced beam section (RBS), a patent of former Luxembourg steel producer ARBED. The RBS has been developed to force the plastic hinge away from the beam-column interface. It relies on the selective removal of beam flange material to reduce the cross sectional area of the beam.

3.4 Through thickness of beam flanges

Through thickness behaviour is one of major concerns when working with welded moment frame connections under seismic loading using the strong column-weak beam concept.
Therefore, tension tests were performed in transverse direction on the flanges of heavy jumbo column sections in HISTAR 460 steel. All specimens broke in either the weld or the pull-plates at stress levels in excess of 690 MPa, the nominal pull-plate stress. The fracture occurred at stresses higher than the strength of the column flange because of the existence of triaxial constraint of the column flange material. This created hydrostatic tension stresses that raised the apparent through-thickness strength. Lamellar tearing did not occur in any of the tested joints and it was concluded that the through-thickness strength does not need to be explicitly checked in the seismic design of welded beam-to-column connections.

4. COST SAVINGS

Over 500 high-rise buildings in U.S. and over 1500 buildings worldwide have been built with ArcelorMittal sections since today due to their significant cost-saving potential. When used as columns in buildings, for girders or as tension members in trusses, the new generation of HISTAR beams enables substantial savings in:

- structural weight,
- material costs,
- fabrication costs,
- transportation and erection costs,
- Foundation costs.

HISTAR 460 compared to grade S355 of ArcelorMittal is available without an extra cost for the steel grade. In case full advantage can be taken from the higher yield strength, a HISTAR 460 beam is ~25% lighter than a comparable section in S355 so that the economical advantage on the material side alone is 25%. The savings are even larger in case HISTAR 460 can be used instead of S235.

5. SUSTAINABILITY

HISTAR steels are predominantly produced from scrap in state-of-the-art electric arc furnaces (EAF). In comparison to the conventional integrated blast furnace route, the EAF production route allowed for substantial reductions in energy consumption and emissions of particles and gases (Table 1).

**Tab. 1:** Environmental advantages of the EAF route in Luxembourg (1993/1998)

<table>
<thead>
<tr>
<th>Emission particles</th>
<th>Reduction of 99%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission CO2</td>
<td>Reduction of 78%</td>
</tr>
<tr>
<td>Emission waste</td>
<td>Reduction of &gt;70%</td>
</tr>
<tr>
<td>Consumption water</td>
<td>Reduction of &gt;50%</td>
</tr>
<tr>
<td>Consumption energy</td>
<td>Reduction of 56%</td>
</tr>
</tbody>
</table>

The QST process operates without external supply of energy and substantially reduces the use of alloying elements. In fact, the QST process allows to up-cycle steel scrap as the constructional performance of a beam in HISTAR steel is by far superior to the performance of a standard beam.

Apart from the general advantages of steel structures with regard to sustainability (clean construction sites and fast erection through prefabrication, easy dismantling and re-erection or recycling), HISTAR grades enable the building industry to:

- Reduce its overall steel consumption
- Reduce the impact of transportation of material due to lower weight
• Design slender load carrying elements occupying less space in a building
• Design bold and outstanding structures.

6. SURFACE PROTECTION BY HOT-DIP GALVANIZATION

It is often stated in literature that fine-grained high yield strength steels have a more critical behavior during galvanization than conventional structural steels. Recent tests have however confirmed that construction components in HISTAR grades behave the same during hot-dip galvanizing as when compared to other structural steels. It can even be stated that HISTAR grades with high notch toughness characteristics feature a better behavior towards fissuring than other steels. In any case, it is of outmost importance for all fabricated structural components to perform stress relieving in the critical areas prior to galvanizing. Indeed, the residual stresses from rolling and fabrication will be superimposed by additional internal stresses from differential elongation of the beam parts during the dipping in the hot zinc bath and may sum up to a level which exceeds the mechanical properties of the steel.

7. CONCLUSION

In a first step QST steel research has enabled to put on the market high strength steel with high properties of ductility and weldability. In a second step high strength steel has been introduced and their performances fully recognized in the Eurocodes. These two steps have created favourable conditions for innovative economical steel design in applications like composite bridges, earthquake resistant systems, cellular beams and fire engineering.

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