HIGH STRENGTH STEEL FOR IMPROVEMENT OF SUSTAINABILITY

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INTRODUCTION

The selection of building materials may significantly influence the sustainability criteria. Life cycle costs, resource efficiency, recyclability and environmental impact are of particular relevance. Until now, the potential of steel with its wide range of strength classes, mechanical and technological properties has been utilized in civil engineering only insufficiently. In the building sector large amounts of material are used. Therefore, increased application of high strength steel does not only improve life cycle assessment and economy, but also the competitiveness of steel structures and the technological advantage of the companies involved in the value added process.

1 GENERAL

Currently, the fundamentals of description and evaluation of the environmental quality of buildings as well as for the documentation of environmentally relevant information on building products are standardized by ISO/TC59/SC17 and CEN/TC350. The lack of binding rules requires the considering of sustainability criteria on the principle of incentives. After the planning and construction process certificates of different rating systems (e.g. BREEAM, DGNB, Green Star, HQE or LEED) are awarded. Besides social benefits there are incentives with regard to intrinsic value and marketability of real estates and buildings.

Sustainability criteria should present objective and science based criteria that as far as possible and practicable – are based on measurable quantities and correspond to the particular type of building. By the choice of material, dimensioning of components and design features influence can be exerted on how particular sustainability criteria are met. This significantly influences life cycle costs, utilization of resources, environmental impact, recyclability and waste accumulation.

Energy and material efficiency are of special significance due to energy consumption and large mass flows in the steel and construction industry. Optimizations in steel production as well as optimizations in making and using steel products are two ways to raise resource efficiency and to reduce negative environmental impacts at the same time.

In the past decades there already was achieved considerable progress referring to raw material and energy requirements, CO₂ emissions and water demand in steel making. Thus, average energy consumption per tonne of crude steel reduced by half in Northern America, Japan and Europe in the past 35 years [1]. There also has been achieved great progress in optimizing the making and use of steel products. In this case the automotive industry and its suppliers play a pioneer role. By applying high strength steel lightweight components were developed that nevertheless have outstanding crash characteristics [2].

2 HIGH STRENGTH STEEL IN CONSTRUCTION ENGINEERING

The development of mechanical and technological properties of steel decisively progressed in the past decades. Today, weldable steel plates with yield strengths of up to 1300 N/mm² are available. In the past high strength steels were not applied on a large scale, but for special purposes, as e. g. in bridge, offshore and power plant construction. Among others, reasons for this could be found in absence of special design and fabrication standards, lack of supply and experience in processing.

The different parts of EN 1993 comprise steel grades up to S460. Part 1-12 contains additional rules for the extension of EN 1993 including steel grades up to S700. Necessary design rule modifications are presented, that need to be observed when applying high strength steels. It recommends the application of quenched and tempered steels S500 up to S690 in quality Q/QL/QL1 according to
EN 10025-6 as well as thermomechanically rolled steel for cold forming S500 MC to S700MC according to EN 10149-2. Further recommendations are regulated in specific National Annexes by the states participating in the Eurocode programme.

By various production processes (Fig. 1) high yield strengths can be generated if the steel is of suitable chemical composition. Besides heat treatment by normalizing, normalized rolling, hardening and tempering there were developed thermo-mechanical treatment processes that allow a reduction of alloying constituents by making use of micro-alloying elements, reducing the final rolling temperature down to the $\gamma-\alpha$ transformation range if applicable combined with differently accelerated cooling rates and self tempering. While having comparable strength properties these steels are easier to process and of higher toughness as compared to conventional production processes.

3 LIFE CYCLE ASSESSMENT

Life cycle assessment provides decision support to determine the further development of materials, products and buildings. ISO 14040 describes the principles and framework of life cycle assessment (LCA). ISO 14044 specifies requirements and provides guidelines for their implementation. LCA studies comprise four phases. The first phase defines the scope of the study including system boundaries and level of detail. The specifications depend on the object of investigation and the intended application of the study. The second phase is life cycle inventory (LCI) involving the determination of all input and output data with regard to the system under investigation. The third phase aims at impact assessment. Complementary to the life cycle inventory it provides additional information on assessment and evaluation of life cycle inventory results and their environmental relevance. Life cycle inventory data of the same environmental impact will be summarised to impact categories (Table 1, [3]). The last phase deals with the interpretation of results.

The present database for environmental product declarations in the field of steel constructions is not satisfactory. It does not represent the variety of steel materials, heat treatment processes, shapings, surface coatings and possible combinations with other materials. Moreover, there is a lack of information on structural steel work, utilization phase and dismantling (Fig. 2, [4]).

In general assessment of steel products is based on a crude steel mix of primary and secondary steel. In recent years there were applied the assessment methods cut-off, closed-loop and multi step approach as well as the approach of crude steel mix with credits. There are essential differences in estimating the proportion of scrap in crude steel production and recycling credits, taking into account product reuse as well as creation of additional scrap resources (avoidance of primary steel production [5], Fig. 3).
Table 1. Criteria for the assessment of the ecological quality and factors of importance (DGNB [3])

<table>
<thead>
<tr>
<th>category</th>
<th>criterion</th>
<th>factor of importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>impacts on the global and local environment</td>
<td>Global warming potential (GWP)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Ozone depletion potential (ODP)</td>
<td>0,5</td>
</tr>
<tr>
<td></td>
<td>Photochemical ozone creation potential (POCP)</td>
<td>0,5</td>
</tr>
<tr>
<td></td>
<td>Acidification potential (AP)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Eutrophication potential (EP)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Risks for the local environment</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Other impacts on the global environment</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Microclimate</td>
<td>0,5</td>
</tr>
<tr>
<td>utilization of resources and waste accumulation</td>
<td>Non-renewable primary energy demand</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Total primary energy demand and share of renewable primary energy</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Drinking water demand and volume of waste water space demand</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Land use</td>
<td>2</td>
</tr>
</tbody>
</table>

Fig. 2. Demand for information: module to describe the life cycle [4]

Fig. 3. Comparison of ecological indicators [6]

4 ENVIRONMENTAL IMPACT OF VARIOUS STEELS

Starting from identical assessment approaches for crude steel and identical dimensions after rolling, various steel grades mainly differ in their alloying constituents and heat treatment processes (Fig. 1 and 4). As with quenched and tempered steels particularly alloying constituents such as molybdenum, chromium and silicon as well as heat treatment essentially influence life cycle assessment.
The gain in strength due to the application of micro-alloying elements in combination with thermomechanical rolling offers great advantages (Fig. 4, [6]).

Fig. 5 shows the relation of CED, GWP_{100} and AP for heavy plates made of various steel grades compared to the expenses for a S235J2. Based on these indicators and in combination with the factors of importance, listed in Table 1, an estimation of the environmental impact determines necessary savings of 3.3 to 17.1% of steel consumption as compared to the application of S235J2 (Table 2, [6]).

Table 2. required weight saving ΔG in [%] compared to steel grade S235J2 [6]

<table>
<thead>
<tr>
<th></th>
<th>S355J2</th>
<th>S420N</th>
<th>S460N</th>
<th>S420M</th>
<th>S460M</th>
<th>S460Q</th>
<th>S500Q</th>
<th>S550Q</th>
<th>S620Q</th>
<th>S690Q</th>
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<tr>
<td>heavy plates</td>
<td>6,6</td>
<td>9,3</td>
<td>10,6</td>
<td>3,3</td>
<td>4,1</td>
<td>10,2</td>
<td>11,1</td>
<td>13,4</td>
<td>15,5</td>
<td>17,1</td>
</tr>
<tr>
<td>rolled sections</td>
<td>6,7</td>
<td>8,8</td>
<td>9,9</td>
<td>3,4</td>
<td>4,2</td>
<td>10,0</td>
<td>10,7</td>
<td>12,6</td>
<td>14,2</td>
<td>15,6</td>
</tr>
</tbody>
</table>

Fig. 4. Cumulated energy demand (CED) for heavy plates (closed-loop-approach) made of various steel grades [6]

Fig. 5. Relation of CED, GWP_{100} and AP of heavy plates for various steel grades referring to S235J2 [6]

5 EFFECTIVE APPLICATION OF HIGHER STRENGTHS STEEL

The application of higher strength steels is advantageous when an increase in strength enables a reduction of steel consumption. This will not only improve life cycle assessment but also the economic efficiency of constructions. Fig. 6 shows a relative price comparison for heavy plates of various steel grades. The comparison bases on average prices provided by different producers in the German market [6]. Compared to the increase in strength there is only a moderate increase in price that may be compensated by appropriate weight savings.
Mass reduction requires that the resistance of a structural element will not be dominated by buckling or fatigue resistance. Furthermore, criteria of serviceability – such as limits for deflections and for dynamic effects (e.g. minimal vibration frequency) – should not determine the dimensions.

The required dimensions of a tension bar are significantly affected by material strength. The cross-sectional areas can be reduced reciprocally in proportion to yield strength. For butt welds with a constant included angle the weld volume increases with the square of the plate thickness. For this reason reduction of plate thickness has positive effects on welding production. (Fig. 7).

High strengths positively influence steel consumption, if stability sensitive members are in a range of compact and medium slenderness. Fig. 8 shows the buckling resistance of a columns made of a hollow section (SHS 300x16) for different buckling lengths and steel grades. It shows that the differences decrease, when the buckling length increases. In conventional storey buildings with buckling lengths of columns between 3 and 5 m, the high strengths have a very positive impact on resistance. The reverse conclusion is, that smaller cross-sections may used for the same requirements of resistance.

For structures, where the weight has a significant influence on the structural design, mass reduction has a double positive effect: The action effects of the elements are reduced and thus further savings of materials are possible. Examples are large-span structures, such as bridges; exhibition, storage and production halls as well as stadium roofs.

The application of higher steel strength may also improve functional aspects. In story buildings long-span beams allowed a reduction of columns and walls and thus a flexible floor plan design. The storey height and thus the building volume to be heated can be reduced by beams with lower height. Columns reduce the rentable space of buildings and leads to restrictions in utilization. Especially in storey buildings with high column loads the cross sections may reduce by application of high strength steels.
6 ACKNOWLEDGMENT

High strength steels will become more and more relevance in building construction. Due to the enlargement and adaption of technical rules, such as Eurocode 3, material standards and manufacturing guidelines, this trend will be supported. Technical assistance for planning and execution as well as better availability of sections and plates out of high straight steels are important for the transfer to the construction industry. In the end, it is a matter of competitiveness in the national and international market, in which steel producers and processors, manufacturers and developers of construction products, planning engineers as well as the processing steel construction companies are involved.

REFERENCES