RUUKKI STRUCTURAL HOLLOW SECTIONS FOR FUNCTIONAL DESIGN ACCORDING TO EUROCODE 3

Ruukki cold-formed structural hollow sections are manufactured of state of the art steels by the latest tube manufacturing technology, conform to or exceed the requirements of European harmonized standard EN 10219-1&2 and enable design and execution in conformity with Eurocode 3 (EN 1993) and EN 1090.

Unrestricted weldability
Compliance with Eurocode 3 requirements for welding in the corner area and welding is permitted without restrictions.

Cost efficient buckling resistance
Wide range of available dimensions and steel grades provide for design of optimal structures with cost-efficient buckling resistance comparable with hot-finished sections.

Usable at extremely low temperatures
Satisfy the requirements to avoid brittle fracture down to operating temperatures
Tmd = –50°C or lower.

Excellent low temperature ductility and impact toughness
Due to the excellent low temperature properties, even after welding, the transition temperature T40J is very low, typically below -50 °C, including the corner area.

Proven fire resistance
During fire the loss of strength takes place slowly and evenly and conforms with the requirements of Eurocode 3.

Excellent fatigue resistance
The fatigue resistance is equal or better than hot-finished products, well suitable for use in dynamically loaded structures and machinery and equipment.

Ruukki Structural hollow sections for functional design according to Eurocode 3

Contents

Introduction

Tubular materials enable steel structures, which are both architecturally and aesthetically impressive and also efficient structures from an engineering point of view. Cold-formed hollow sections are the dominant tubular construction material and Ruukki is a recognized manufacturer of these products.

Economical and environmental constraints favour cost competitiveness and higher strength. The cold-forming route is naturally economical and can mostly adapt to higher strength too.

Increased strength opens up the chance to reduce wall thicknesses and the weight of the structure and brings benefits:

- Easier processing
- Lower transportation costs or increased payloads
- Possibility of realizing structures that are not feasible with lower-strength steels
- Reduction of environmental impact and Life cycle cost

The applicability, weldability and reliability of cold-formed Ruukki structural hollow sections will be highlighted in order to enable a functional design and execution of economical and reliable structures for a wide range of applications in conformity with Eurocode 3 and EN 1090. The benefits of using high strength steel grades will be highlighted as well.

Detailed data, assistance and examples on efficient design according to Eurocode 3 is available in "Structural Hollow Sections. EN 1993 – Handbook 2012. Rautaruukki Oyj" [1].

For available dimensions and steel grades kindly visit www.ruukki.com.

[1] *Ongelin, P., Valkonen, I.: Structural Hollow Sections. EN 1993 – Handbook 2012 . Rautaruukki Oyj.*

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Standards

In Europe we have harmonized standards for two main types of hollow sections:

- EN 10210-1&2 – Hot-finished structural hollow sections of non-alloy and fine grain steels
- EN 10219-1&2 – Cold-formed welded structural hollow sections of non-alloy and fine grain steels

The manufacturing methods of these products are different. As specified in the standards the mechanical characteristics, dimensions, tolerances and cross-sectional properties are slightly different. Thus the products are not necessarily fully compatible.

"Hot-finished" stands for manufacturing method where the final forming process of the tube is carried out hot, with final deformation above 700 ºC, or where the tube is cold-formed and then subsequently full body heat treated at a temperature above 550 ºC.

"Cold-formed" stands for manufacturing method, where the main forming process of the tube is carried out at ambient temperature and the product is supplied without additional heat treatment, except the weld seam may be heat treated. Ruukki Structural hollow sections conform to or exceed the requirements of European standard EN 10219-1&2.

The standard EN 1090-2 – Execution of steel structures and aluminium structures, Part 2: Technical requirements for steel structures, Table 2 recognizes equally EN 10210 and EN 10219 hollow sections as structural steel products. Thus EN 1090 is neutral concerning one's choice between these products.

Eurocode 3 — Design of steel structures, recognizes both EN 10210 and EN 10219 hollow sections in relevant parts. Both products are generally accepted and equally treated by Eurocode. Thus Eurocode does not generally differentiate EN 10219 and EN 10210 hollow sections or point out differences between these materials.

There are, however, some exceptions like:

- Welding in cold-formed zones [EN 1993-1-8, ch 4.14, Table 4.2]
- Buckling resistance [EN 1993-1-1, Table 6.2, curve "c" vs. curve "a"]

The designer shall be aware and make the most of these differences!

Welding in corner area

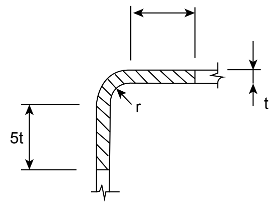
Rectangular hollow sections are well suited to the manufacture of welded structures. But welding may cause ageing and reduction of impact toughness of cold-formed rectangular hollow section corners. Consequently, Eurocode 3 includes restrictions on welding in the corner area [2].

EN 1993-1-8, Ch 4.14 Welding in cold-formed zones, states [2]:
"Welding may be carried out within a length 5t either side of a cold-formed zone provided that one of the following conditions is fulfilled:

- The cold-formed zones are normalized after cold-forming but before welding
- The r/t-ratio satisfy the relevant value obtained from Table 4.2. in EN 1993-1-8"

Table 4.2: Conditions for welding cold-formed zones and adjacent material [2].

r/t	Strain due to cold-forming (%)	Maxium thickness (mm)		
		Generally		Fully killed Aluminium-killed steel (Al ≥0,02 %)
		Predominantly static loading	Where fatigue predominates	
≥ 25	≤ 2	any	any	any
≥ 10	≤ 5	any	16	any
≥ 3,0	≤ 14	24	12	24
≥ 2,0	≤ 20	12	10	12
≥ 1,5	≤ 25	8	8	10
≥ 1,0	≤ 33	4	4	6



NOTE Cold formed hollow sections according to EN 10.219 which do not satisfy the limits given in Table 4.2 can be assumed to satisfy these limits if these sections have a thickness not exceeding 12,5 mm and are Al-killed with a quality J2H, K2H, MH, MLH, NH or NLH and further satisfy C≤0,18%, P≤0,020% and S ≤0,012%.

In the other vases welding is only permitted within a distance of 5ft from the corners if it can be shown by test that welding is permitted for that particular application.

As specified in the NOTE, welding in the corner area of EN 10219 hollow sections is permitted providing the thickness does not exceed 12,5 mm and the chemical analysis satisfies C ≤ 0,18 %, P ≤ 0,020 %, S ≤ 0,012 %. Ruukki structural hollow sections comply with these requirements and welding is permitted without restrictions.

[2] EN 1993-1-8 (2010): Eurocode 3: Design of steel structures. Part 1-8: Design of joints; Including Corrigendum dated July 2009.

Buckling resistance – Design of hollow section columns

Cold-formed and hot-finished hollow sections as tension and flexural members are treated in an identical manner by EN 1993-1-1, but the lower level of residual stresses of hot-finished is recognized by assigning these sections to a more favourable buckling curve "a" when designing compression members. For cold-formed the buckling curve "c" applies and it yields up to 22 % lower buckling strength than curve "a", see figure 1.

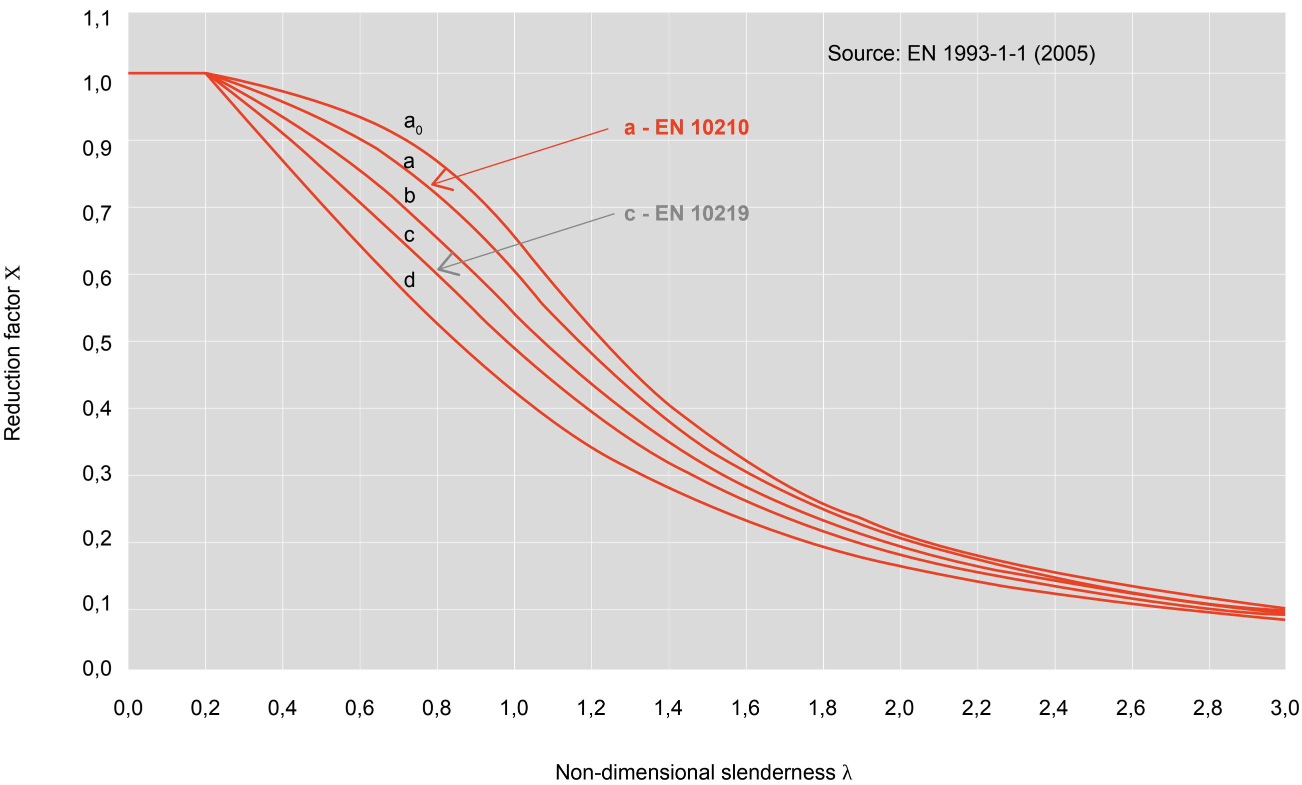


Fig. 1 The buckling curves, figure 6.4 in EN 1993-1-1 [3].

Dimensions (b; h; t) and steel grade (Yield strength) have strong effect on buckling resistance. Small changes may have strong influence on buckling and cost. Sensible and economical design requires that the designer is aware and makes the most of these differences.

Puthli & Packer [4] have compared the cost of buckling resistance with German price conditions for using cold-formed and hot-finished rectangular hollow sections. They concluded, that the next higher wall thicknesses may need to be chosen for cold-formed sections to obtain comparable buckling strength, Table 1.

Using cold-formed hollow sections with increased wall thickness implies 15..20 % higher weight, but equal or lower cost, than using hot-finished. The buckling resistance is not necessarily a cost issue!

[3] EN 1993-1-1 (2010): Eurocode 3: Design of steel structures. Part 1-1: General rules and rules for buildings.
[4] Puthli, R.,Packer, J. A.: Structural design using cold-formed hollow sections, Steel Construction 6 (2013), No. 2, pp 150-157.

Table 1 Grade S355J2H hollow sections with comparable buckling resistance. Cost premium (€/metre, Germany) of hot-finished structural hollow sections (HF) to EN 10210 relative to cold-formed structural hollow sections (CF) to EN 10219.

Dimension [mm]	Cost premium of three distributors		
	A	B	C
200 x 200 x 10 HF / 200 x 200 x 12,5 CF	+25 %	+33 %	+7 %
150 x 150 x 6,3 HF / 150 x 150 x 8,0 CF	+23 %	+5 %	+10 %

Source: Puthli, R.,Packer, J. A.: Structural design using cold-formed hollow sections, Steel Construction 6 (2013), No. 2, pp 150–157

Increased strength in combination with optimal dimensions offers a cost efficient opportunity. Choosing appropriate dimensions and grade S420MH, enables comparable buckling strength and weight as using hot-finished grade S355J2H sections, figure 2. Depending on actual market prices the use of grade S420MH offers cost savings anywhere up to 20 %.

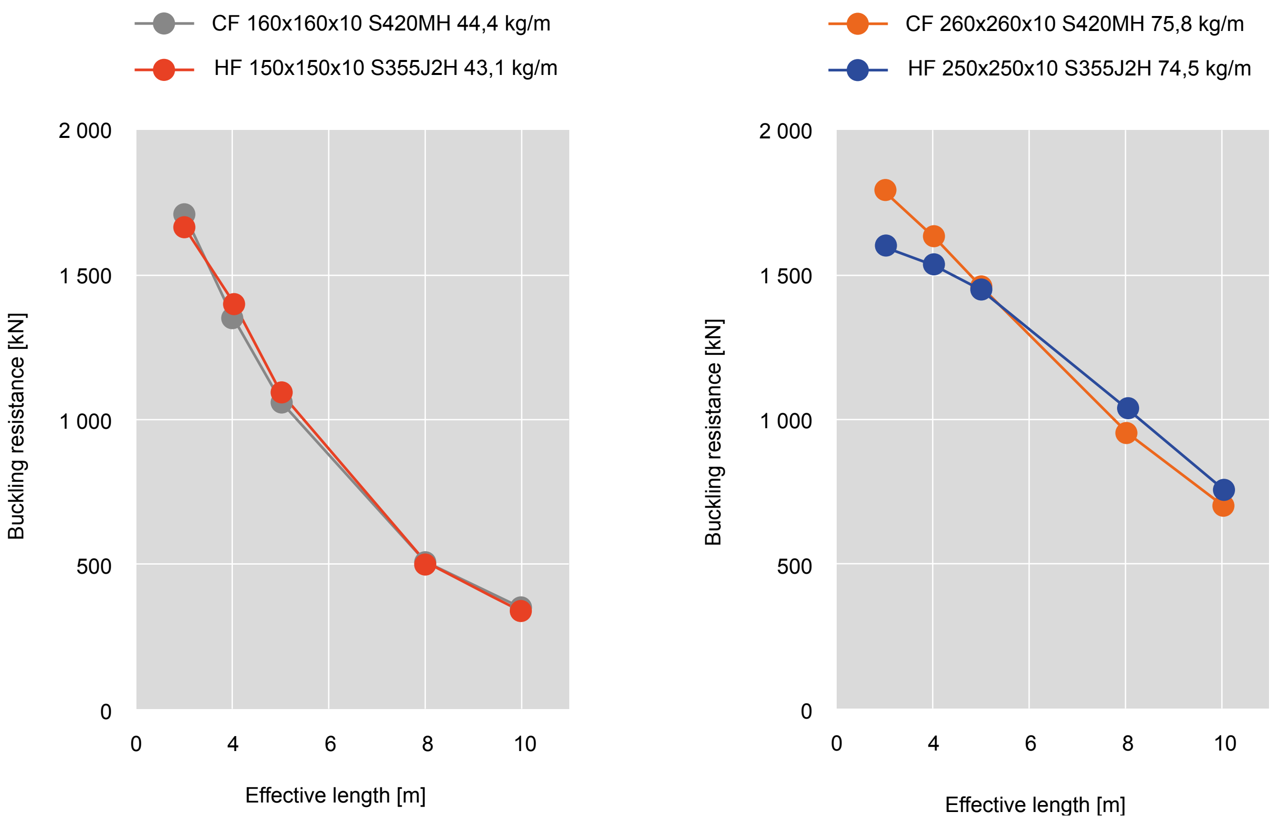


Fig. 2 Buckling resistance comparisons according to EN 1993-1-1. Cold-formed EN 10219 grade S420MH vs. hot-finished EN 10210 grade S355J2H.

Buckling resistance – Design of concrete filled hollow section columns

Concrete filled columns have the same buckling resistance, irrespective of the product, hot-finished or cold-formed. In both cases the buckling curve to be chosen for circular and rectangular hollow sections in Eurocode 4 Part 1-1 [5] is "a" for reinforcement ratio ≤ 3%, and "b" for reinforcement ratio between 3% and 6%. This is irrespective of whether it is a weak or strong axis concerned for RHS. The reinforcement ratio is defined as the ratio between the cross-sectional area of the longitudinal steel reinforcement and the concrete cross-section. In case of concrete filled columns both products, cold-formed and hot-finished, perform equally, but the use of cold-formed hollow sections means lower cost [4].

Welded joints

Joint resistance typically governs the selection of hollow section members. EN 1993-1-8, chapter 7 [6] gives the design rules for hollow section joints. Both cold-formed and hot-finished sections have the same joint resistance.

The load carrying- and deformation capacities of X- and K-joints made of cold-formed hollow sections of fine grain steels and of hot-finished hollow sections in grade S355J2H have been carefully studied in a CIDECT sponsored RFCS-project and by Björk [7; 8; 9].

The fabrication method, cold-formed or hot-finished, does not give rise to any significant differences in the behaviour of welded joints, figure 3.

X-joints made of Ruukki high strength cold-formed tubes (double grade S420MH/S355J2H and S460MH) fulfil also the Eurocode 3 requirements, figure 4.

Properly designed and welded joints, made of Ruukki EN 10219 structural hollow sections, conform to the Eurocode 3 requirements for deformation and load carrying capacity even at low temperatures and as hot-dip galvanized.

[5] EN 1994-1-1 (2010): Eurocode 4: Design of composite steel and concrete structures. Part 1-1: General rules and rules for buildings.

[6] EN 1993-1-8, Eurocode 3: Design of steel structures – Part 1-8: Design of joints, 2005

[7] Salmi, P., Kouhi, J., Puthli, R., Herion, S., Fleischer, O., Espiga, F., Croce, P., Bayo, E., Goni, R., Björk, T., Ilvonen, R., Suppan, W.: Design rules for cold-formed structural hollow sections, Report EUR 21973 EN, European Commission, 2006.

[8] Björk, T.: Ductility and ultimate strength of cold-formed rectangular hollow section joints at subzero temperatures. Dissertation Thesis, Acta Universitatis Lappeenrantaensis 233, 2005

[9] Ritakallio, P., Björk, T.: Low-temperature ductility and structural behaviour of cold-formed hollow section structures – progress during the past two decades. Steel Construction 2 (2014), No. 2.

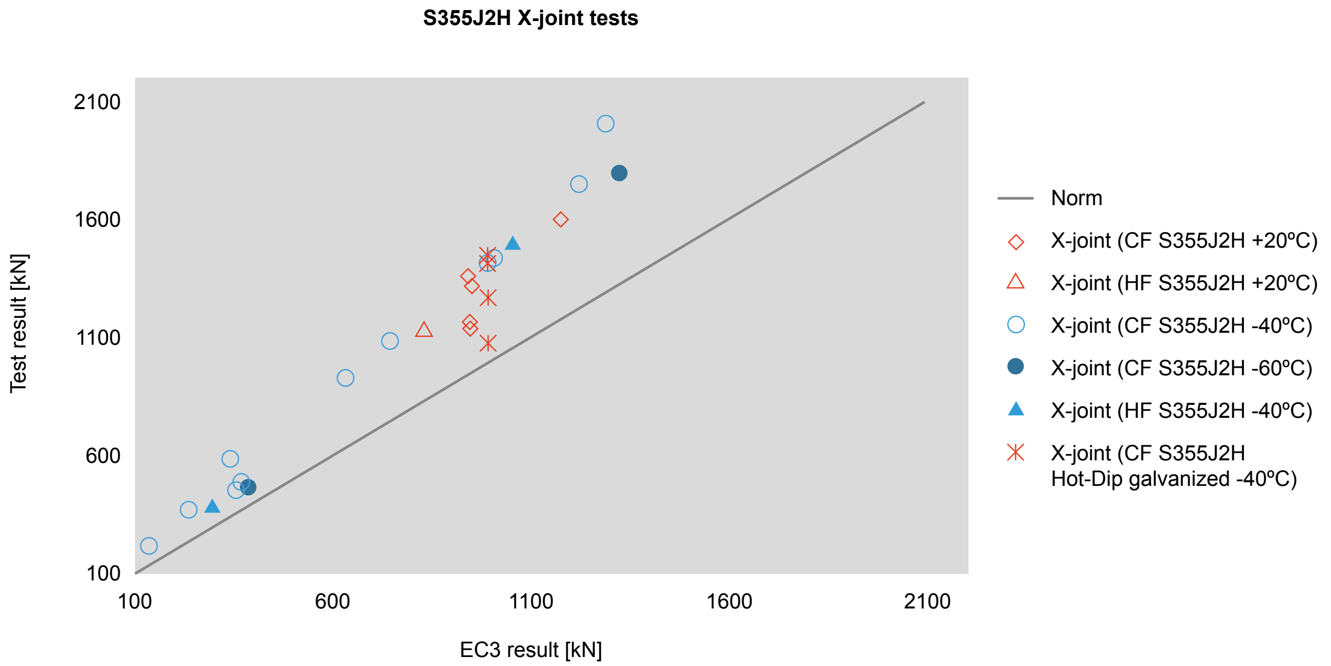


Fig. 3 Results from X-joints made of S355J2H cold-formed and hot-finished tubes, and also including some hot-dip galvanized joints [9].

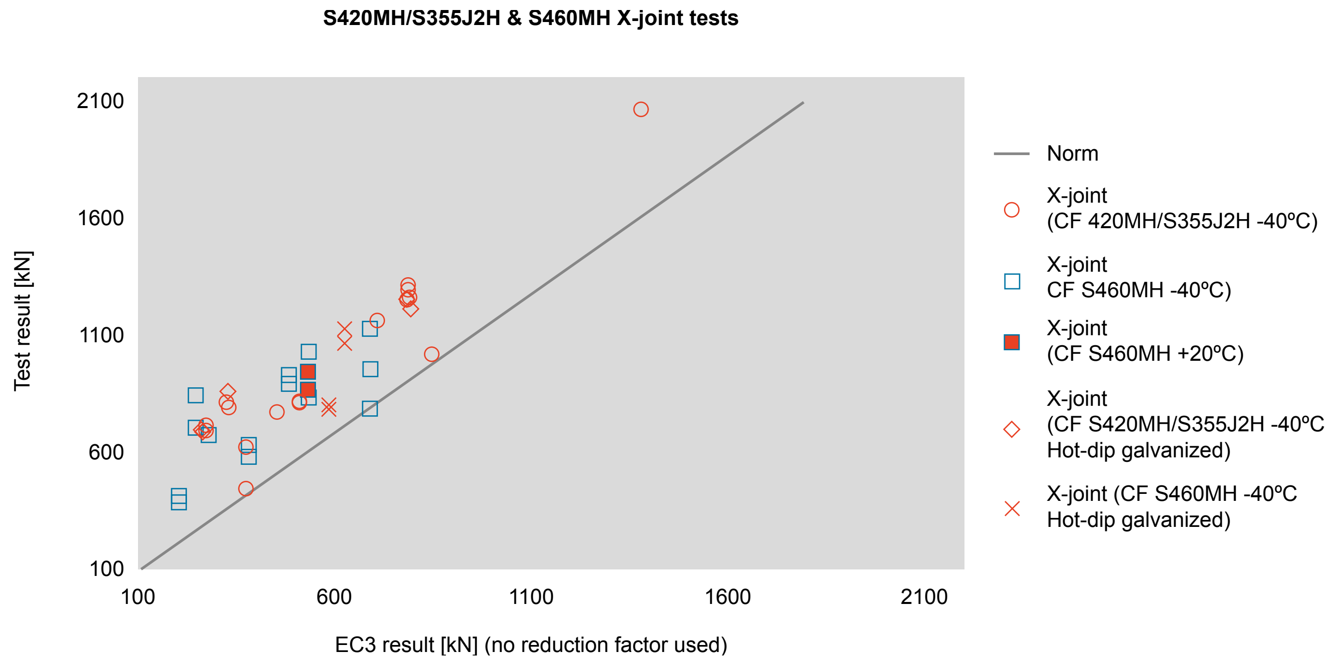


Fig. 4 Results from X-joints made of high strength cold-formed tubes, and also including some hot-dip galvanized X-joints [9].

Lowest operating temperature to avoid brittle fracture

EN 1993-1-10 [10] gives rules for choice of material to avoid brittle fracture of steel structures. These rules are not yet sufficient for cold-formed hollow sections. The JRC Report [11]: "Choice of steel material to avoid brittle fracture for hollow section structures", gives supplementary guidance for the use of EN 1993-1-10 on welded structures made of cold-formed hollow sections. The JRC Report provides a conservative procedure for evaluation of the lowest allowable reference temperatures TEd and operating temperatures Tmd for EN 10219 hollow section structures.

Ongelin and Valkonen [1] have applied the JRC procedure for Ruukki cold-formed structural hollow sections concluding the following outcome:

- For rectangular Ruukki hollow sections the lowest operating temperature Tmd ≤ −75°C for grade S420MH and Tmd ≤ −90°C for grade S355J2H, table 2.
- For circular Ruukki hollow sections the lowest operating temperature Tmd is from −70°C to −125°C depending on dimension and grade, table 5.4 in [1]

Thus Ruukki hollow sections are usable in all practical climatic conditions.

Table 2. The lowest allowed reference temperature TEd and operating temperature Tmd. Square and rectangular structural hollow sections, table 5.3 in [1].

Square and rectangular structural hollow sections a)									
Steel grade		EN 10219 structural hollow sections				structural hollow sections EN 10219 by Ruukki			
		Impact toughness		The lowest design value of temperature b)		Impact toughness		The lowest design value of temperature b)	
		Testing temperature	Charpy-V impact energy	T_{Ed} (°C)	T_{md} (°C)	Testing temperature	Charpy-V impact energy	T_{Ed} (°C)	T_{md} (°C)
S235	JRH	20 °C	27 J	-85	-50	20 °C	27 J	-85	-50
S355	J2H	-20 °C	27 J	-95	-60	-40 °C c)	40 J c)	-125 d)	-90 d)
	MH	-20 °C	40 J	-100	-65	-20 °C	40 J	-100	-65
	MLH	+50 °C	27 J	-120	-85	-50 °C	27 J	-120	-85
S420	MH	-20 °C	40 J	-90	-55	-40 °C e)	40 J e)	-110 f)	-75 f)
	MLH	-50 °C	27 J	-110	-75	-50 °C	27 J	-110	-75
S460	MH	-20 °C	40 J	-85	-50	-20 °C	40 J	-85	-50
	MLH	-50 °C	27 J	-105	-70	-50 °C	27 J	-105	-70

a) Fabcation dimension range by Ruukki
-square and rectangular: t = max. 12,5 mm

b) T_{md} = TEd – $\Delta T_{\varepsilon.cf}$
where
T_{Ed} is the reference temperature according to the Table 5.1
T_{md} is the anbient temperature of the nember, when the reference temperature has been corrected with the forming factor $\Delta T_{\varepsilon.cf}$
$\Delta T_{\varepsilon.cf}$ is determined using the simplified method presented in clause 5.2.1 [13]

c) Ruukki double grade S420MH/S355J2H.
d) Ruukki double grade S420MH/S355J2H when designed basing on the grade S355.

e) Ruukki double grade S420MH/S355J2H.
f) Ruukki double grade S420MH/S355J2H when designed basing on the grade S420.

- The values in the Table have been calculated with wal thickness t = 12,5 mm. When using thinner wall thicknesses the value are on the safe side.

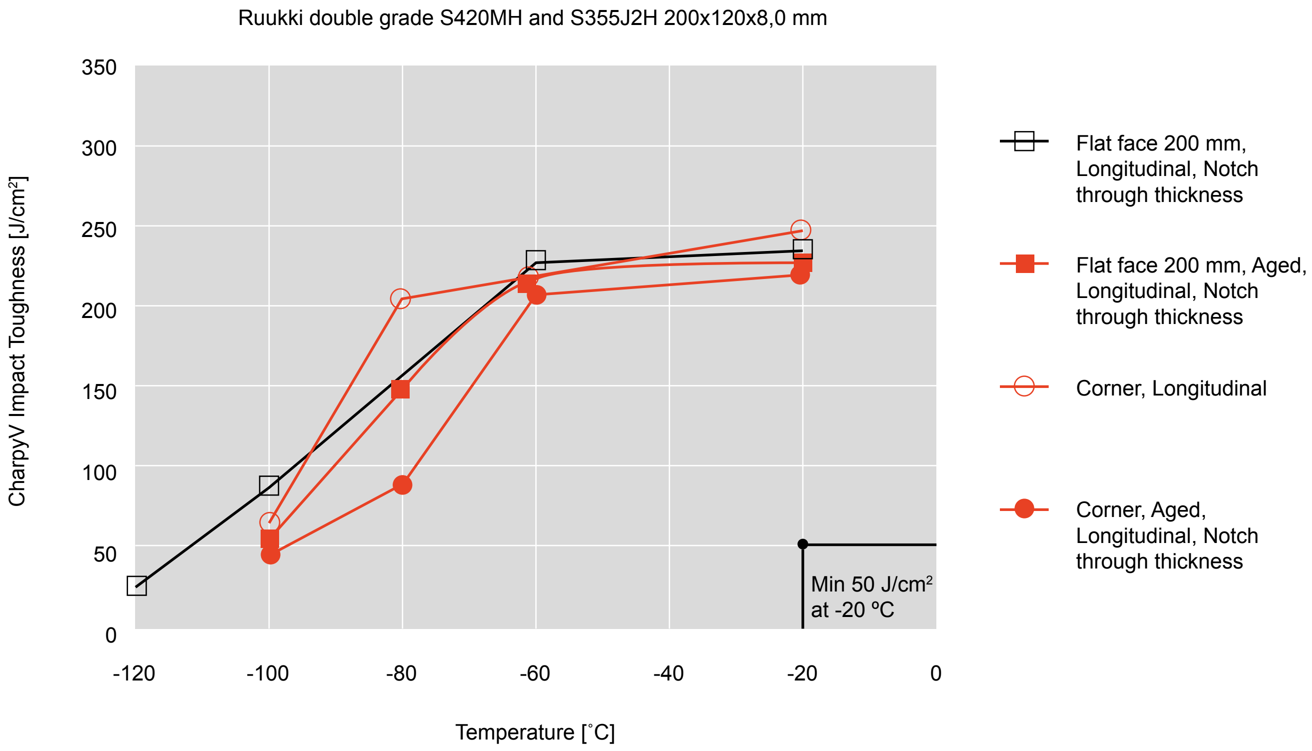
- The values in the Table have been calculated on on the stress level of serviceability limit state qEd=0,75fy, on which level calculated values can be used as a conservative values also at lower stress levels.

[10] EN 1993-1-10 (2010): Eurocode 3: Design of steel structures. Part 1-10: Material toughness and through thickness properties.

[11] Feldmann, M., Eichler, B., Kühn, B., Stranghöner, N., Dahl, W., Langenberg, P., Kouhi, J., Pope, R., Sedlacek, G., Ritakallio, P., Iglesias, G., Puthli, R.S., Packer, J.A. and Krampen, J. (2012): Choice of steel material to avoid brittle fracture for hollow section structures. Report EUR 25400 EN, European Commission Joint Research Centre Scientific and Policy Report for the evolution of Eurocode 3, ISBN 1831-9424.

Low temperature ductility and impact toughness

Ruukki EN 10219 cold-formed structural hollow sections are manufactured of state of the art micro alloyed and thermo mechanically rolled and controlled cooled low carbon steels by the latest tube manufacturing technology. This combination generates the excellent low temperature properties of Ruukki structural hollow sections. Even after ageing or welding, the transition temperature T40J is very low, typically below -50 °C, including the corner area, figure 5.



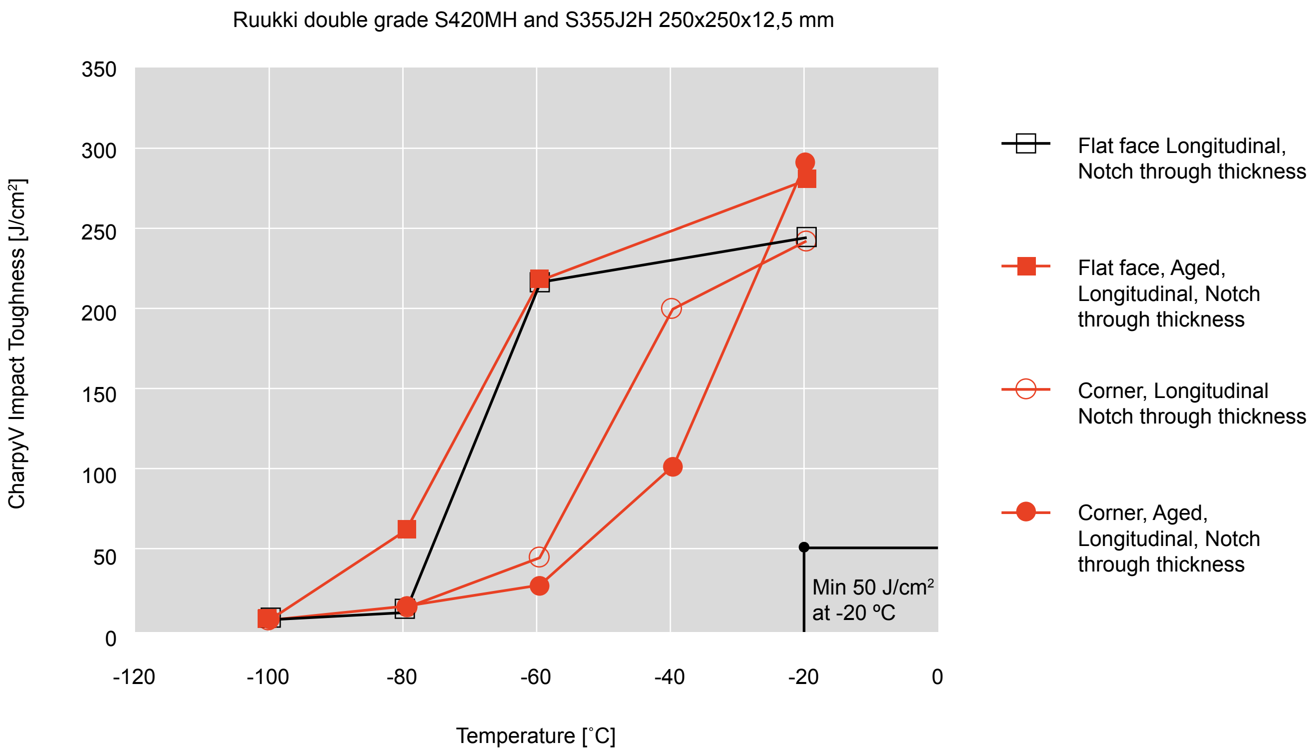


Fig. 5 Impact of ageing (30 min / 250 oC) on Charpy-V impact toughness of Ruukki double grade S420MH/S355J2H structural hollow sections.

Both cold-forming and welding may substantially reduce the low temperature ductility of conventional S355J2 steels [12; 13]. There is a risk that the Charpy-V testing according to EN 10219-1 with specimens taken from the flat face is not sufficiently representative for the corner areas. Therefore the impact toughness in the corner zone of rectangular cold-formed section may be reduced to substandard level. This is not relevant in case of Ruukki structural hollow sections, figure 5.

From time to time it is also claimed that the low temperature toughness of hot-finished hollow sections is superior to cold-formed hollow sections. The CIDECT study "Notch Toughness of Cold-Formed Hollow Sections,Report 1B-2/03, CIDECT, Geneva, 2003" [14] comprises a careful analysis and testing of CharpyV-impact toughness of structural hollow sections and demonstrates the diversity of the quality in the market place.

Using the data available in the CIDECT study [14], some brochures [15; 16] set forth comparisons of hot-finished products vs. selected low quality cold-formed products. These comparisons are done in order to feed biased impression on the quality of cold-formed products.

In order to correct this erroneous message figure 6 comprises the best products included in the CIDECT study [14]. Contrary to common belief the CIDECT study confirms that the low temperature toughness of cold-formed hollow sections is equally good as hot-finished hollow sections.

Thanks to fit-for-purpose feed material and tube manufacturing, Ruukki structural hollow sections have the "best in class" low temperature properties. Even after welding, the transition temperature T40J is very low, typically below -50 °C, including the corner area.

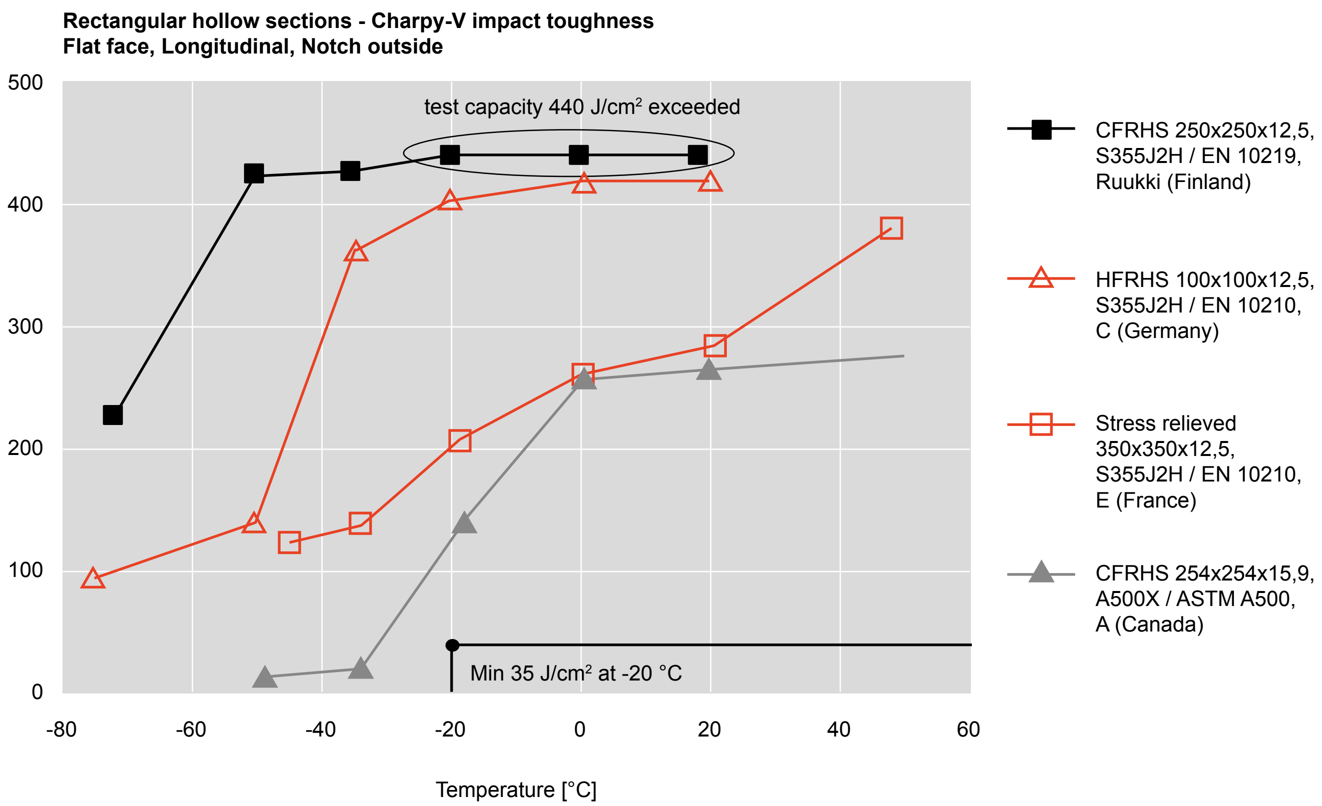


Fig. 6 Charpy-V impact toughness of the best hot-finished and cold-formed products included in the CIDECT Study "Notch Toughness of Cold-Formed Hollow Sections" [13].

[12] *STEEL: A Handbook for Material Research and Engineering Volume 1: Fundamentals, Springer Verlag, Verlag Stahleisen mbH Düsseldorf, 1992.*

[13] *Soininen, R.: Haurasmurtumisen alkaminen ja eteneminen niukkahiilisissä rakenneteräksissä, Lic. Tech. Thesis, Oulun Yliopisto, 1975 (in Finnish)*

[14] *Kosteski, N., Packer, J. A., Puthli, R. S.: Notch Toughness of Cold-formed Hollow Sections, Report 1B-2/03, CIDECT, Geneva, Switzerland, 2003.*

[15] *Celsius ® 355: the ultimate choice, Hot structural hollow sections. Tata Steel 2011*

[16] *Hot Rolled MSH Sections. A step ahead in quality. Vallourec & Mannessmann, V&M 303_6e*

Fire design

According to Puthli and Packer [4] the reduction in product properties between cold-formed and hot-finished sections under fire loading is small, and hence there is no differentiation between the two product types in simple fire design.

The strength of Ruukki structural hollow sections at elevated temperatures has been carefully studied [17]. While the steel temperature is increasing, the loss of strength takes place slowly and evenly and conforms to the requirements of EN 1993-1-2 [18] with good margin, figure 7. Ruukki cold-formed hollow sections can be safely used according to the EN 1993-1-2 rules for structural fire design.

As pointed out by Puthli and Packer [4], according to EN 1993-1-2 [18] and EN 1994-1-2 [19] under fire loading hot-finished and cold-formed hollow sections, both unfilled and concrete filled, have equal buckling resistances. In fire designs cold-formed and hot-finished perform equally, but the use of cold-formed hollow sections means lower cost [4].

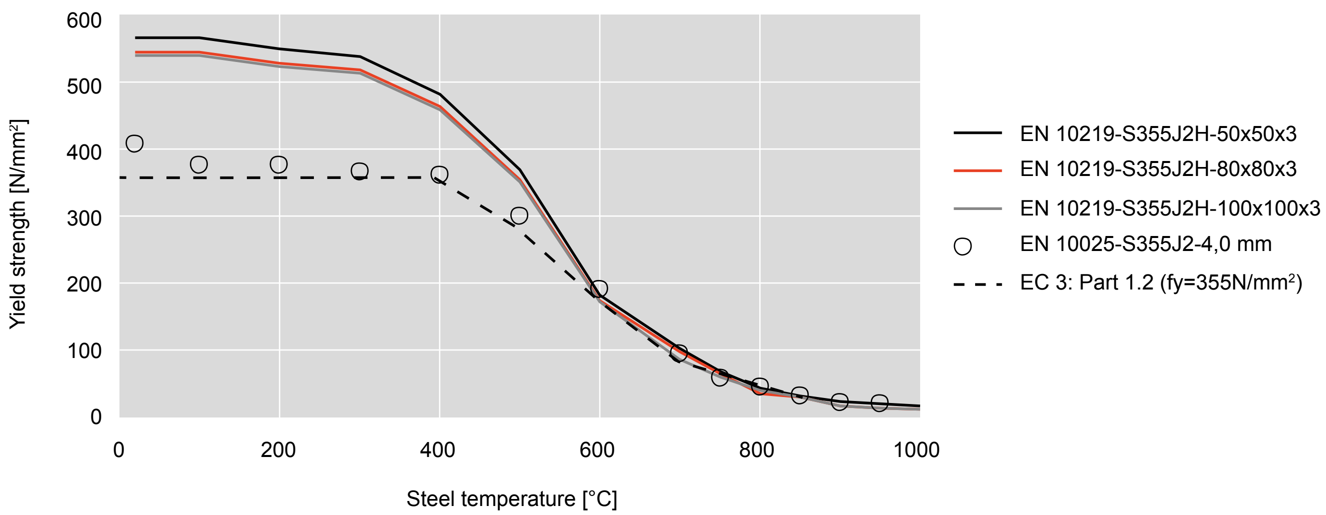


Fig. 7 Yield Strength of Ruukki S355J2H structural hollow sections and of Hot Rolled 4 mm plates, grade S355J2 acc. to EN 10025 in the temperature range of 20°C to 950°C with a heating rate of 20°C/minute [17].

[17] Outinen J., Mäkeläinen P.: Effect of High Temperature on Mechanical Properties of Cold-Formed Structural Steel. Ninth International Symposium and Euroconference on Tubular Structures, Düsseldorf, Germany. Proceedings book: Tubular Structures IX, Edited by: Puthli, R., Herion, S., A. A. Balkema, pp. 439-444, Niederlande, 2001.

[18] EN 1993-1-2 (2010): Eurocode 3: Design of steel structures. Part 1-2: General rules – Structural fire design.

[19] EN 1994-1-2 (2010): Eurocode 4: Design of composite steel and concrete structures. Part 1-2: General rules – Structural fire design.

Strength after heating

Ruukki structural hollow sections tolerate heating and cooling without significant deterioration of the tensile properties up to 580 oC [20]. Thus they are suitable for flame straightening, if necessary. As an example the strength of Ruukki double grade after heating and cooling is shown in figure 8.

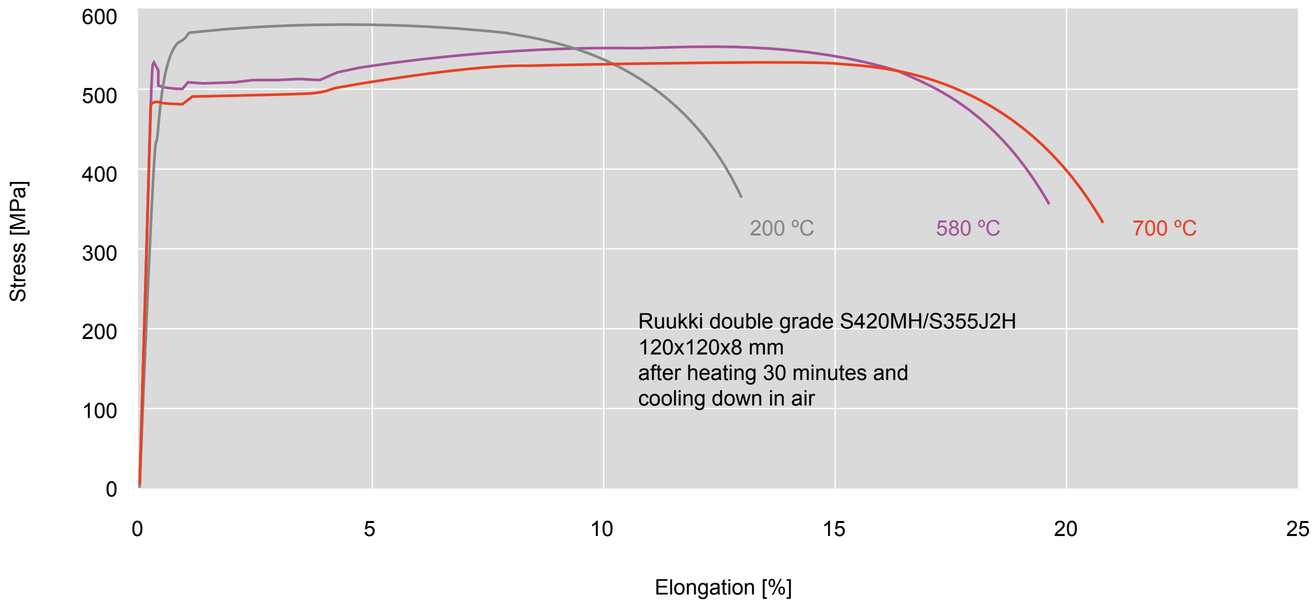


Fig. 8 Tensile Strength of Ruukki double grade S420MH/S355J2H structural hollow section 120x120x8 mm after heating 30 minutes at 200°C, 580°C and 700°C and cooling down in air [21].

[20] Outinen J., Mäkeläinen P.: Mechanical properties of structural steel at elevated temperatures and after cooling down, Fire and Materials 2004, 28, pp 237-251.

[21] Ritakallio P.: Tragverhalten und Gebrauchseigenschaften von kaltgefertigten rechteckigen Stahlbau-Hohlprofielen, Stahlbau 82 (2013), Heft 8, S. 564-572.

Fatigue design

For fatigue design, hollow section joints have the same fatigue life irrespective of the product (hot-finished or cold-formed) by both the classification method and the hot-spot stress method. In Eurocode 3, Part 1-9 [22] there is no differentiation between these two product types.

The applicability of cold-formed tubes is sometimes questioned or limited because of doubts on poor fatigue resistance of the cold-formed corner areas. It is also claimed that by choosing hot-finished tubes the problems are automatically avoid-ed.

The fatigue resistance of the cold-formed corner areas of Ruukki structural hollow sections has been carefully tested. The study of Bäckström et. al. [23] confirmed that the cold-formed Ruukki hollow sections exhibit better fatigue resistance than good quality hot-finished products, figure 9. Surface condition and proper storage of the materials is important in case of fatigue loading. For example inside corrosion due to poor storage conditions deteriorates the fatigue resistance to same level with hot-finished products.example inside corrosion due to poor storage conditions deteriorates the fatigue resistance to same level with hot-finished products.

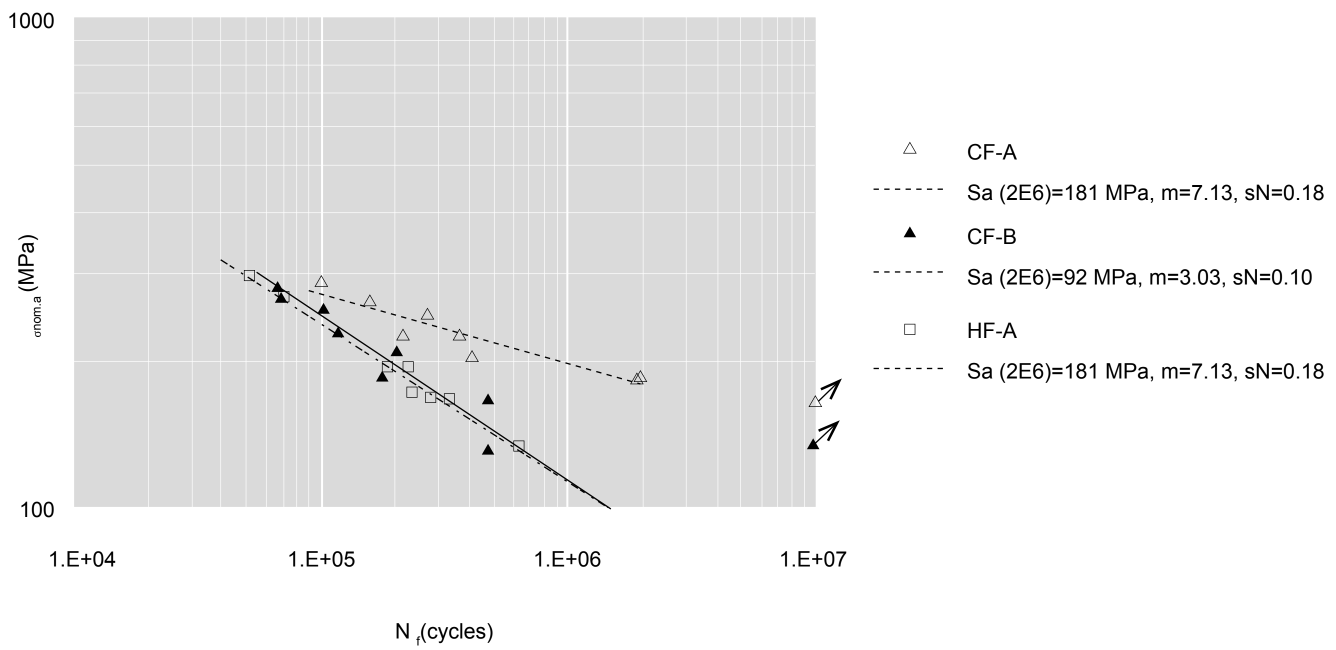


Fig. 9 Fatigue strength of European rectangular hollow section corners as a function of nominal normal stress amplitude, Bäckström et.al. [14].
CF-A: Cold–Formed Ruukki EN10219 –100x100x5 mm;
CF-B: Cold–Formed Ruukki EN10219 –100x100x5 mm inside corroded due to poor storage conditions;
HF-A: Hot-Formed European EN10210 –100x100x5 mm

[22] EN 1993-1-9 (2010): Eurocode 3: Design of steel structures. Part 1-9: Fatigue.
[23] Bäckström, M., Savolainen, M., Ilvonen, R., Laitinen, R.: A new fatigue testing method for the corners of structural hollow sections. Proceedings of Fatigue 2002, Eighth International Fatigue Congress, Stockholm, Sweden, June 2-7, 2002, pp. 277–302.

The CIDECT Study "Fatigue of high strength cold-formed RHS corners. Report 7X-9/06, CIDECT, Geneva, 2006" [24] confirmed that the transverse fatigue strength of cold-formed Ruukki RHS fulfil the requirements (FAT 160) obtained in Eurocode 3 and CIDECT design guides, figure 10.

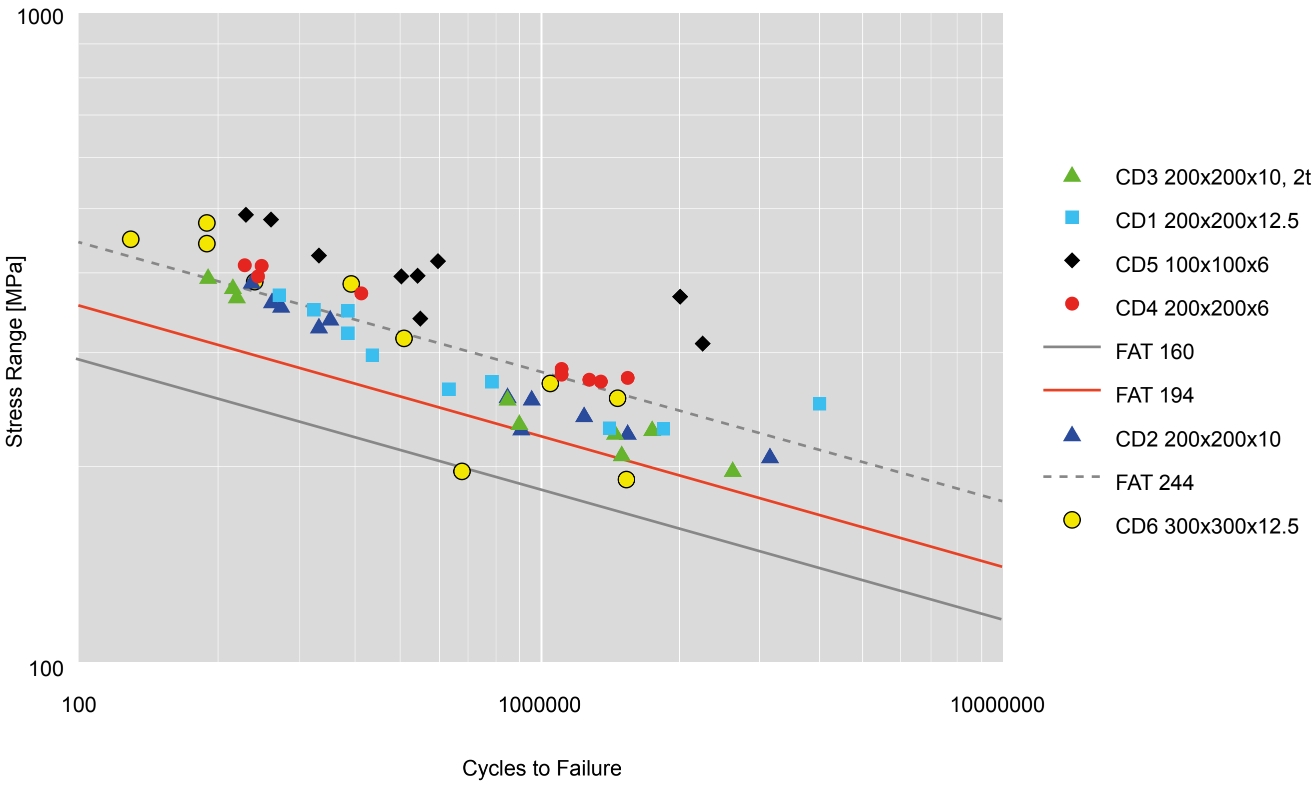


Fig. 10 Fatigue strength of hollow section corners according to Kokkonen and Björk [24]. Mean and characteristic lines for material S355 tests and a design value FAT 160 MPa shown.
CD1→CD5: Cold-formed Ruukki EN10219 – S355J2H
CD3: external corner radius 2t
CD6: cold-formed Ruukki EN10219 – S460MH

[24] Kokkonen, J., Björk, T.: Fatigue of high strength cold-formed RHS corners. Report 7X-9/06, CIDECT, Geneva, 2006.

Hot-dip galvanizing

Hot-dip galvanizing is one prime method for corrosion protection of tubular structures Corner cracking sometimes occurs when hot-dip galvanizing square and rectangular tubes. The problem with corner cracking is generally attributed to Liquid Metal Embrittlement (LME) in association with high residual stresses in the cold-formed rectangular hollow section corners.

Interaction of three conditions is claimed to determine the occurrence of LME [25]:

- Critical level of internal stress, e.g. residual stress due to cold working and welding
- Susceptible material, e.g.: non-aluminium killed steel, high yield to tensile ratio,
- pre-existing micro cracks as a result of forming or adverse chemical composition
- Liquid metal, especially with the presence of impurities or additives.

Thus beside the composition of the zinc bath the quality of the feed material and the hollow section itself are essential features.

The impact of hot dip galvanizing on Ruukki hollow sections has been carefully tested and compared with hot-finished counterparts both on the material level and with welded structures too [26]. These studies confirm that Ruukki EN 10219 hollow sections are not susceptible to LME. The alteration of the joint strength or ductility of welded structures due to hot-dip galvanizing is insignificant and welded structures made of Ruukki EN 10219 hollow sections can be safely corrosion protected by hot-dip galvanizing, figure 3 and 4.

The chemistry of Ruukki EN 10219 hollow sections is adapted to hot dip galvanizing with Silicon content in the range 0,15 % < Si < 0,25 % (Class 3; EN 10025 part 2 to 4) leading normally to an Zn-layer thickness in the order of 100...150 mm depending on hot-dip galvanizing parameters, like dipping time and Zn-bath analysis, like Ni-content.

Hollow sections with Silicon content Si ≤ 0,03 and Si+P ≤ 0,04 % (Class 1; EN 10025 part 2 to 4), leading normally to an Zn-layer thickness in the order of 50...80 mm depending on hot-dip galvanizing parameters, are available by agreement.

[25] *"Galvanizing structural steelwork–An approach to the management of liquid metal assisted cracking. BCSA & GA Publication No. 40/05, 1st Ed, British Constructional Steelwork Association & Galvanizers Association, London, UK, 2005.*

[26] *Ritakallio, P. O.: Cold-formed high-strength tubes for structural applications. Steel Construction, 5 (2012), No. 3, pp. 158-167.*

Summary

Ruukki cold-formed structural hollow sections are manufactured of state of the art steels by the latest tube manufacturing technology, conform to or exceed the requirements of European harmonized standard EN 10219-1&2 and enable design and execution in conformity with Eurocode 3 (EN 1993) and EN 1090.

Ruukki cold-formed EN 10219 hollow sections key features:

- Satisfy the Eurocode 3 requirements for welding in the corner area
- Grade S420MH enables design of structures with comparable buckling strength and weight as using hot-finished grade S355J2H sections but with cost savings anywhere up to 20 %.
- Satisfy the requirements to avoid brittle fracture down to operating temperatures
- Tmd = −50°C or lower.
- Have excellent low temperature properties, even after welding, the transition temperature T40J is very low, typically below -50 °C, including the corner area.
- Welded joints conform to the Eurocode 3 requirements for deformation and load carrying capacity even at low temperatures and as hot-dip galvanized.
- During fire the loss of strength takes place slowly and evenly and conforms with the requirements of Eurocode 3.
- The fatigue resistance is equal or better than hot-finished products, well suitable for use in dynamically loaded structures and machinery and equipment.
- Tolerate heating and cooling without significant deterioration of the tensile properties up to 580 oC and are suitable for flame straightening, if necessary.
- Are not susceptible to Liquid Metal Embrittlement (LME) and can be safely corrosion protected by hot-dip galvanizing.
- Constitute safe, reliable and versatile high-performance structural material for environmentally sound and competitive solutions