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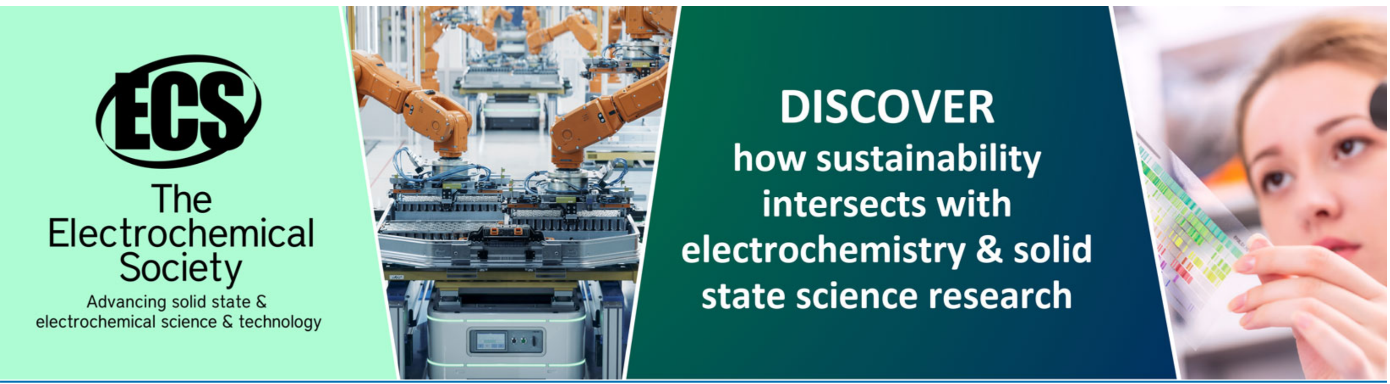

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Effect of ageing on the mechanical properties of cold formed S700 rectangular hollow

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Abstract. The aim of this work is to study the effect of ageing (250 °C for 1 h) on the mechanical properties of the cold formed S700 rectangular hollow section. The investigated hot rolled steel strip was produced thermomechanical rolling followed by direct quenching. The dimension of the investigated hollow section was 120 x 120 x 10 mm and the corner radii and the other tolerances compliant with EN 10219. Tensile properties and Charpy-V impact toughness were determined for the base material and flat and corner area of the hollow section. The results showed that the tensile strength in the corner was slightly higher in comparison with the flat side, revealing higher cold deformation rate in the corner. Ageing increased the strength level relatively higher than cold forming without losing any elongation properties. The impact energies were at the high level at -40 °C and -60 °C in cold formed and aged materials. Even at -80 °C, the CV results were 118 J/cm^2. It is also notable that no difference in CV values between the flat and the corner samples were observed. Thus, the results showed that the flat side specimens testing provides sufficient information of mechanical properties of the cold formed rectangular hollow sections and no need demanding corner sample testing when the structural hollow section is produced by using the thermomechanical controlled and direct-quenched base material. Furthermore, results showed that cold formed S700 is excellent for offshore steels, as steels are used even colder conditions as before.

1 Introduction

Formed steel sections are widely used in construction and engineering applications due to their relatively high strength and stiffness properties. Especially, cold-formed welded hollow sections provide cost efficient and environmentally friendly alternatives compared to hot-formed sections [1]. Cold-formed rectangular hollow sections are manufactured from steel strips to final sections in several cold forming stages. Cold deformation causes work hardening of the material, which resulting in enhanced strength, although a corresponding loss of elongation and toughness. When steels are used even colder climate conditions, the requirements especially for toughness properties are increasing. This increases demands for the steel to behave safety in demanding conditions.

Artificial aging is defined in the EN 10225-4 [2] and DNV standard [3]. The technique of artificial aging is often employed to alter the mechanical properties of ferritic and/or martensitic steels. In traditional ferritic steels, strength generally increases while ductility decreases with increasing thermal exposure due to the tempering. Soininen [4] has been reported that, toughness properties decrease gradually from the base material to the flat side and then to the corner of the hollow section, due to ageing at 250 °C for 30 min. Sun and Packer [5] have shown that the impact toughness properties of the corner area are lower compared to the flat side. Likewise, Guo et al. [6] have shown that corner has

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the highest strength level compared to the flat side, and flat side strengths are higher than raw material. Kaijalainen et al. [7] have been reported that S500 cold formed rectangular hollow section (RHS) produced by the direct-quenched base material has much better toughness properties than conventionally manufactured.

Therefore, aim of this study is to compare microstructure and mechanical properties of direct-quenched S700 in base material, flat and corner area. Additionally, report the effect of artificial ageing on the mechanical properties of the base material and cold formed flat and corner area of RHS.

2 Experimental

Microstructures and mechanical properties of S700 cold formed structural rectangular hollow section (120 x 120 x 10 mm) were investigated. The investigated hot rolled base material (in wt.% 0.05C-1.8Mn-0.2Si-0.08Nb-0.1Ti) was produced by a conventional thermomechanical controlled processing and direct quenching (TMCP-DQ). The yield strength in hot rolled stage was 600 MPa, tensile strength 720 MPa and total elongation was 23 %. Microstructure of the base material was ferrite and bainite with small fraction of carbon rich areas, as can be seen in Figure 1. External corner radius of the hollow section was 25 mm, which is in the middle of EN 10219 tolerance range (20-30 mm for 10 mm) [8]. Artificial ageing was carried out at 250 °C for one hour, which is requirement in the EN 10225-4 standard [2].

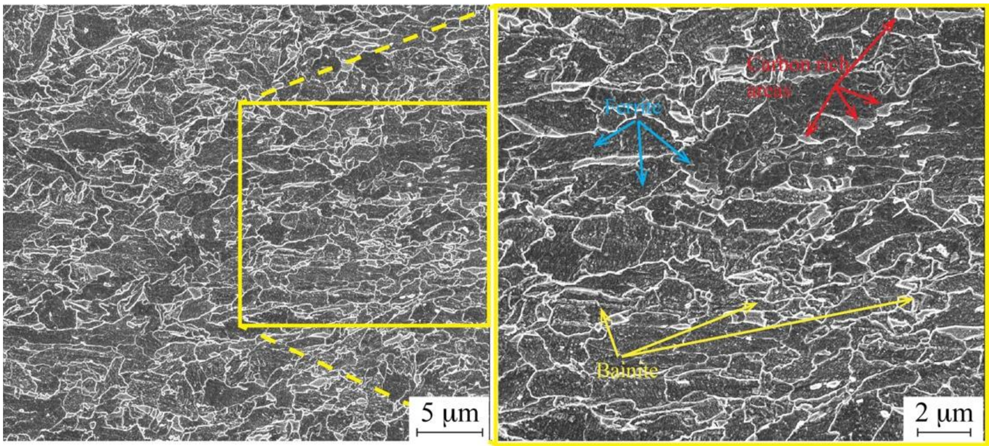

Figure 1. Microstructure of the base material.

General characterization of the transformation microstructures was performed with a laser scanning confocal microscope (LSCM) after nital etched specimens. Grain boundary misorientation distribution and grain sizes were measured using Oxford-HKL electron backscatter diffraction (EBSD) system on the Zeiss Ultra plus field emission scanning electron microscope (FESEM). The FESEM for the EBSD measurements was operated at 15 kV and the step size was 0.3 µm. Grain boundaries of low-angle and high-angle (effective grain size) were determined as equivalent circle diameter (ECD) values with the low (>2.5°) and the high boundary misorientation (>15°), respectively.

Samples for the mechanical testing were water-cut and machined suitable for tensile and Charpy-V tests (Figure 2) in the rolling direction. Sample dimension was 10 x 12 x 70 mm. Tensile tests were carried out using Zwick/Roell Z100 at the room temperature in accordance with the standard EN ISO 6892-1:2016. Charpy-V notch (CVN) impact testing was performed in accordance with the standard EN ISO 148-1:2016 at -40 °C, -60 °C and -80 °C (3 specimens / temperature) using longitudinal (L-T) and transversal (T-L) specimens for base and flat side material and longitudinal specimen for corner (L-T). Sub-size impact test specimen was machined to 5 mm x 10 mm x 55 mm size.

Figure 2. Examples of water-cut Charpy-V impact toughness and tensile test samples from a) flat side and b) corner of rectangular hollow section.

3 Results and discussion

3.1 Microstructure

The microstructures of the base material, flat side and corner area are presented in Figure 3 and grain sizes respectively in Table 1. Over 2.5° results include both low- and high-angle grain boundaries and over 15° results include only high-angle grain boundaries. From the figures of the corner area it can be seen that the outside area microstructure is stretched, and the inside is compressed.

From the EBSD grain boundary measurements and microstructures it can be seen that the flat side and corner area has smaller grain sizes comparing to the base material. From Table 1 it can be seen that there are no clear differences in the grain sizes in the corner area, except the inner corner. The base material has the smallest fraction of low-angle grain boundaries (red color in Figure 3) and the corner areas have the high fraction low-angle grain boundaries, which indicating higher cold forming level as been seen in Ref. [9].

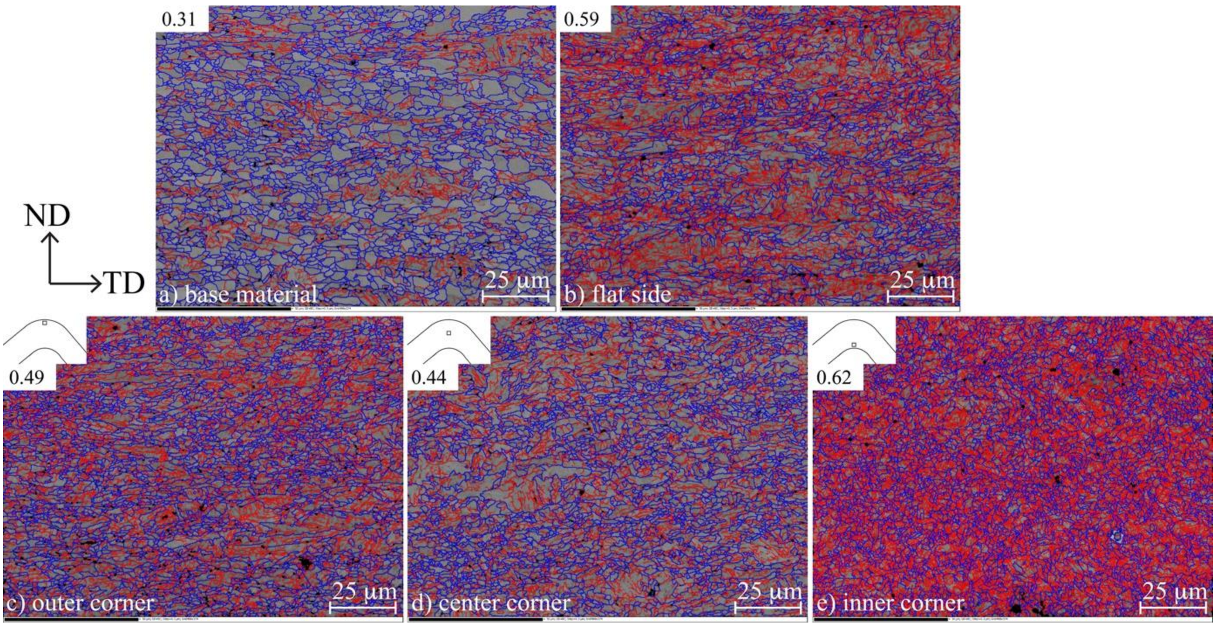

Figure 3. EBSD image quality maps with low- (>2.5°, red) and high-angle (15°-62.7°, blue) boundaries. Microstructures of a) base material, b) flat side, c) outer, d) center and e) inner corner area of the rectangular hollow section. Low-angle grain boundary fractions are also presented.

Table 1. EBSD grain size (equivalent circle diameter, (ECD)) measurements.

	base material	flat side	outer corner	center corner	inner corner
Low-angle boundaries	1.7 μm	1.1 μm	1.0 μm	1.2 μm	0.8 μm
High-angle boundaries	2.6 μm	2.3 μm	2.1 μm	2.2 μm	1.7 μm

3.2 Mechanical properties

Table 2 and Figure 4 present the tensile test results carried out from base, flat side and corner specimens. Generally, from the results can be seen that the higher cold deformation increases the strength values and therefore the tensile strength (R_m) values in the corner area are the highest. Similar results are observed by Walker and Guo et al. [6,10]. About 115 MPa increasing of the tensile strength was observed from the base material to the flat side of the hollow section and from the flat side to the corner area. When comparing the yield strength, the aged base material specimen have increased yield point, which increase the $R_{p0.2}$ value relatively much comparing the others. Ageing increased the tensile strength level ~40 MPa on the flat and corner area. However, there are no notable differences in elongation values between the corner samples, except of the aged flat side specimen.

Table 2. Mean tensile test results of base material, flat side and corner samples. Two sample tested for each material.

	$R_{p0.2}$ (MPa)	R_m (MPa)	A (%)	$R_{p0.2}/R_m$-ratio
Base material	604	719	23	0.84
Base material Aged	670	724	22	0.93
RHS flat side	722	838	9	0.86
RHS flat side Aged	871	886	14	0.98
RHS corner	762	948	10	0.80
RHS corner Aged	785	983	11	0.80

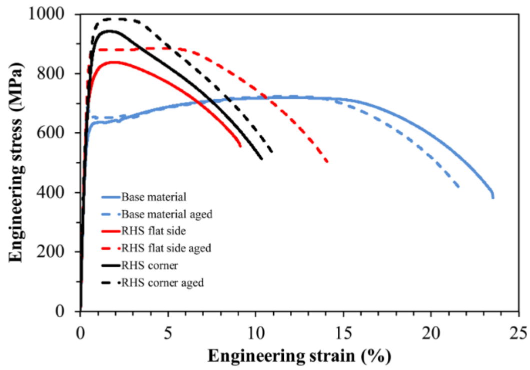

Figure 4. Stress – strain curves of investigated materials.

In the Table 3 it is shown individual and average CVN results of the base material, flat side and corner samples at the testing temperatures -40 °C, -60 °C and -80 °C. At -40 °C impact values are same level, and only some exceptions can notice in transversal direction (T-L) with and without aging. It is also notable that there are no significant differences in the CVN values between the flat (142 J/cm^2) and the corner areas (153 J/cm^2). It can be also seen in Figure 5a, that aging decreases impact energies generally, which corresponding with the study of Soininen [4]. The impact energies are relatively high level at -40 °C and -60 °C when considered strength level in the cold formed and aged materials. Even at -80 °C, the average impact energy is 118 J/cm^2 on the flat side, which is exceeding the requirements of EN 10225-4 and EN 10219 standards in the clearly colder testing temperature than required.

Table 3. Longitudinal (L-T) and transversal (T-L) Charpy-V impact energies of the base material and the flat and corner areas of the hollow section. The sub-size impact test specimens were used.

	-40 °C (J/cm²)			*average*	-60 °C (J/cm²)			*average*	-80 °C (J/cm²)			*average*
Base material L-T	185	160	153	***166***	183	193	180	***185***	163	165	-	***164***
Base material L-T Aged	155	183	158	***165***	158	185	178	***173***	180	85	163	***143***
Base material T-L	158	133	160	***150***	133	98	130	***120***	120	120	-	***120***
Base material T-L Aged	103	133	113	***116***	118	128	130	***125***	133	65	-	***99***
RHS flat L-T	158	143	125	***142***	135	140	133	***136***	115	135	105	***118***
RHS flat L-T Aged	133	153	123	***136***	60	128	-	***94***	80	103	85	***89***
RHS flat T-L	123	123	118	***121***	103	90	45	***79***	70	75	73	***73***
RHS flat T-L Aged	85	88	98	***90***	38	38	83	***53***	40	50	43	***44***
RHS corner L-T	153	158	150	***153***	145	158	118	***140***	93	68	100	***87***
RHS corner L-T Aged	140	163	140	***148***	70	115	100	***95***	-	-	-	-

In the Figure 5b it is presented a relationship between the tensile strength and impact toughness at -60 °C. From the Figure 5b it can be seen three different phenomenons, (1) aging has a minor effect on the impact energies of the base material when testing direction is same. When changing the CVN testing direction from longitudinal (L-T) to transverse (T-L) drops the base material energy levels by 60 J/cm². Similar trend can be noticed on the RHS samples as well, where the transversal energies are lower. (2) Artificial ageing increases the strength level, while the toughness values decrease. (3) The corner sample of the hollow section has 110 MPa higher tensile strength compared to the flat side, but still having better impact energy at -60 °C than the flat side. Typically higher strength level decreasing the toughness properties, especially for the corner specimens [5]. However, in this study direct-quenched material improves toughness properties. Similar improvement of the corner impact energies has been found in S500 grade cold formed structural hollow sections, when base material has been direct-quenched [7]. Therefore, it could be concluded that corner sample testing is not necessary, because the flat side specimens testing provides sufficient information of the mechanical properties of the cold formed rectangular hollow sections when using direct-quenched feedstock material.

In the future, in order to improve the knowledge of the mechanical properties of cold-formed structural hollow sections produced by direct-quenched feed stock material, the transition curves with the transition temperature (T28J) or ductile-to-brittle transition temperature (DBTT) must be studied. In addition, supplementary tensile test specimens should be tested to obtain more accurate strength and elongation results.

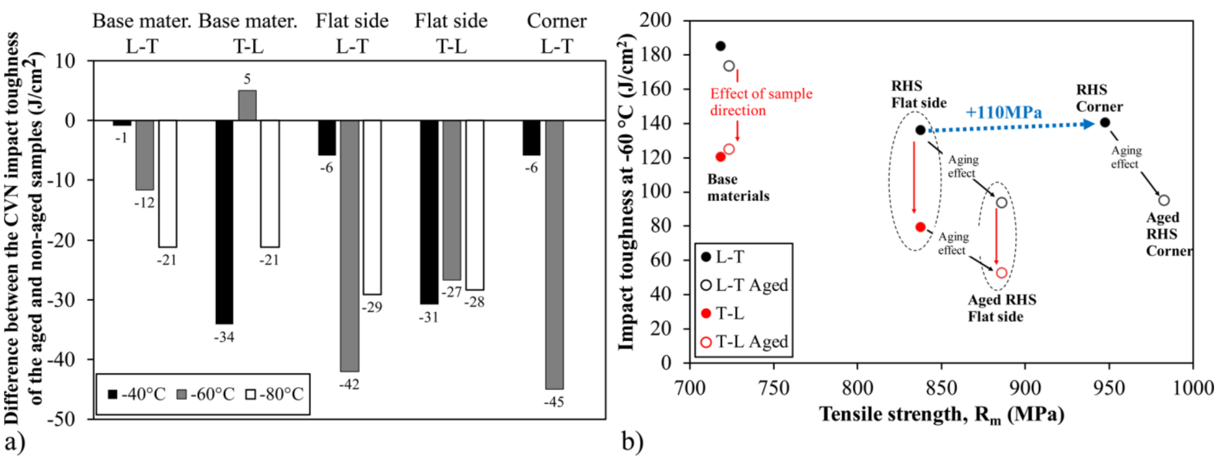

Figure 5. a) Effect of the ageing on the impact toughness. b) Relation between the tensile strength and the impact energies at -60 °C of the investigated conditions.

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4 Summary

Mechanical properties and microstructure of the cold-formed rectangular hollow section manufactured by using the direct-quenched feed stock material was studied. Additionally, the effect of the artificial ageing on the mechanical properties was investigated. Microstructural characterization showed that the inside area of the hollow section corner was compressed, and the outside area was stretched. However, no large differences in the grain sizes between the different corner areas were observed. The corner area had smaller grain sizes comparing to the base material. Higher cold deformation increases the strength values and therefore the strength in the corner areas was the highest. Artificial ageing (250 °C, 60 min) increases the strength level, while the toughness values decrease. The most remarkable result in this study was that the corner area of the hollow section had better impact energy values even at -60 °C than the flat side although having clearly higher tensile strength level. Therefore, it can be concluded that the time consuming corner sample testing is not necessary, and the flat side testing provides the sufficient information of the mechanical properties of the cold formed rectangular hollow sections up to S700, when the cold formed structural hollow section is produced by using the thermomechanical controlled and direct-quenched feed stock material.

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References

[1] Puthli R and Packer J A 2013 Structural design using cold-formed hollow sections *Steel Constr.* **6** 150–7
[2] EN 10225-4 2009 Weldable structural steels for fixed offshore structures. Technical delivery conditions, *European Standard, CEN*
[3] DNVGL-CP-0347 2016 Steel hollow sections
[4] Soininen R 1996 Fracture behaviour and assessment of desing requirements against fracture in welded steel structures made of cold formed hollow sections (Lappeenranta University of Technology, Lappeenranta, Finland)
[5] Sun M and Packer J A 2014 Charpy V-notch impact toughness of cold-formed rectangular hollow sections *J. Constr. Steel Res.* **97** 114–26
[6] Guo Y J, Zhu A Z, Pi Y L and Tin-Loi F 2007 Experimental study on compressive strengths of thick-walled cold-formed sections *J. Constr. Steel Res.* **63** 718–23
[7] Kaijalainen A, Mourujärvi J, Tulonen J, Steen P and Kömi J 2020 Effect of direct quenching on the mechanical properties of cold formed S500 rectangular hollow section *Procedia Manuf.* **50** 777–83
[8] 10219 E 2006 *Cold formed welded structural hollow sections of non-alloy and fine grain steels, European Standard, CEN*
[9] Kaijalainen A, Mourujärvi J, Tulonen J, Steen P and Kömi J 2021 Improvement on Impact Toughness of Cold Formed S420 Steel by Direct Quenching *Mater. Sci. Forum* **1016** 648–53
[10] Walker A 1975 *Design and Analysis of Cold-formed Sections* (Wiley)