European Commission

JRC SCIENCE FOR POLICY REPORT

Choice of Steel Material to Avoid Brittle Fracture for Hollow Section Structures

Background documents in support to the implementation, harmonization and further development of the Eurocodes

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.

Editors: Pinto A., Amorim-Varum H. and Acun B.

2012

EUR 25400 EN

Joint Research Centre

Contact information
Name: Artur Pinto
Address: Joint Research Centre, Via Enrico Fermi 2749, TP480, 21027 Ispra (VA), Italy
E-mail: artur.pinto@jrc.ec.europa.eu
Tel.: +39 0332 78 6062

JRC Science Hub
https://ec.europa.eu/jrc

JRC72702

EUR 25400 EN

PDF	ISBN 978-92-79-61761-4	ISSN 1831-9424	doi:10.2788/463273

Luxembourg: Publications Office of the European Union, 2012

How to cite: 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.; Choice of Steel Material to Avoid Brittle Fracture for Hollow Section Structures; EUR 25400 EN; doi:10.2788/463273

Choice of Steel Materials to Avoid Brittle Fracture for Hollow Section Structures (Re-edition)
European cold-formed hollow sections in general exhibit better toughness properties than required by EN 10219. However, limits in applying the toughness related rules for the choice of steel material in EN 1993 1 10 to cold-formed hollow sections still constitute barriers to free marketing. By requests from European producers a conservative assessment procedure has been developed which is based on toughness measurements and a concept using effective strains.

Note:
This publication replaces the report "Choice of Steel Material to Avoid Brittle Fracture for Hollow Section Structures" with ISBN number 978-92-79-25592-2 and PUBSY request number JRC72702. The corrections made in the new edition of the report are referring to page A-103 of Annex A that was showing incorrectly in the previous edition.

Choice of Steel Material to Avoid Brittle Fracture for Hollow Section Structures

M. Feldmann, B. Eichler, B. Kühn, N. Stranghöner, W. Dahl, P. Langenberg, J. Kouhi, R. Pope, G. Sedlacek, P. Ritakallio, G. Iglesias, R.S. Puthli, J.A. Packer and J. Krampen

Background documents in support to the implementation, harmonization and further development of the Eurocodes

Joint Report

Prepared under the JRC – ECCS cooperation agreement for the evolution of Eurocode 3 by representatives of CEN / TC 250 and CIDECT

Editors: A. Pinto, H. Amorim-Varum and B. Acun

The European Convention for Constructional Steelwork (ECCS) is the federation of the National Associations of Steelwork industries and covers a worldwide network of Industrial Companies, Universities and Research Institutes.

http://www.steelconstruct.com/

The International Committee for the Development and Study of Tubular Structures (CIDECT) joins together the research resources of major hollow section manufacturers to create a major force in the research and application of hollow steel sections worldwide.

http://www.cidect.com/

Contact information

Address: Mies-van-der-Rohe-Straße 1, D-52074 Aachen

E-mail: sed@stb.rwth-aachen.de

Tel.: +49 241 80 25177

Fax: +49 241 80 22140

http://www.stb.rwth-aachen.de

Photo on cover page by courtesy of Ruukki. It shows the fabrication process of a cold-formed circular hollow section with welding.

Foreword

The **construction sector** is of strategic importance to the EU as it delivers the buildings and infrastructure needed by the rest of the economy and society. It represents more than **10% of EU GDP and more than 50% of fixed capital formation**. It is the largest single economic activity and the biggest industrial employer in Europe. The sector employs directly almost 20 million people. In addition, construction is a key element for the implementation of the **Single Market** and other construction relevant EU Policies, e.g.: **Environment and Energy**.

In line with the EU's strategy for smart, sustainable and inclusive growth (EU2020), **Standardization** will play an important part in supporting the strategy. The **EN Eurocodes** are a set of **European standards** which provide common rules for the design of construction works, to check their strength and stability against live and extreme loads such as earthquakes and fire.

With the publication of all the 58 Eurocodes parts in 2007, the implementation of the Eurocodes is extending to all European countries and there are firm steps towards their adoption internationally. The Commission Recommendation of 11 December 2003 stresses the importance of **training in the use of the Eurocodes**, especially in engineering schools and as part of continuous professional development courses for engineers and technicians, noting that they should be promoted both at national and international level.

In light of the Recommendation, DG JRC is collaborating with DG ENTR and CEN/TC250 "Structural Eurocodes" and is publishing the Report Series '**Support to the implementation, harmonization and further development of the Eurocodes**' as JRC Scientific and Technical Reports. This Report Series include, at present, the following types of reports:

1. Policy support documents – Resulting from the work of the JRC and cooperation with partners and stakeholders on 'Support to the implementation, promotion and further development of the Eurocodes and other standards for the building sector.

2. Technical documents – Facilitating the implementation and use of the Eurocodes and containing information and practical examples (Worked Examples) on the use of the Eurocodes and covering the design of structures or their parts (e.g. the technical reports containing the practical examples presented in the workshops on the Eurocodes with worked examples organized by the JRC).

3. Pre-normative documents – Resulting from the works of the CEN/TC250 Working Groups and containing background information and/or first draft of proposed normative parts. These documents can be then converted to CEN technical specifications.

4. Background documents – Providing approved background information on current Eurocode part. The publication of the document is at the request of the relevant CEN/TC250 Sub-Committee.

5. Scientific/Technical information documents – Containing additional, non-contradictory information on current Eurocodes parts which may facilitate implementation and use, preliminary results from pre-normative work and other studies, which may be used in future revisions and further development of the standards. The authors are various stakeholders involved in Eurocodes process and the publication of these documents is authorized by the relevant CEN/TC250 Sub- Committee or Working Group.

Editorial work for this Report Series is **assured by the JRC** together with partners and stakeholders, when appropriate. The publication of the reports type 3, 4 and 5 is made after approval for publication from the CEN/TC250 Co-ordination Group.

The publication of these reports by the JRC serves the purpose of implementation, further harmonization and development of the Eurocodes, However, it is noted that neither the Commission nor CEN are obliged to follow or endorse any recommendation or result included in these reports in the European legislation or standardization processes.

This report is part of the so-called Background documents (Type 4 above). It is a joint JRC-ECCS report and it part of a series of background documents in support to the implementation and further evolution of Eurocode 3.

The editors and authors have sought to present useful and consistent information in this report. However, **users of information contained in this report must satisfy themselves of its suitability for the purpose for which they intend to use it**.

The report is available to download from the "Eurocodes: Building the future" website (http://eurocodes.jrc.ec.europa.eu).

Ispra, June 2012

Artur Pinto and Bora Acun

European Laboratory for Structural Assessment (ELSA)

Institute for the Protection and Security of the Citizen (IPSC)

Joint Research Centre (JRC) – European Commission

Humberto Amorim-Varum

Departamento de Engenharia Civil

Universidade de Aveiro

Acknowledgement

This report, initiated by producers of cold-formed hollow sections, has been prepared in cooperation with experts from CEN/TC 250, CEN/TC 135 and CIDECT, together with experts from ferrous metallurgy who have already been involved in the development of EN 1993-1-10.

Main sources of the report are the JRC-report EUR 23510 EN-2008 “Commentary and worked examples to EN 1993-1-10 - Material Toughness and through thickness properties and other toughness oriented rules in EN 1993”, as well as information and material data from experts of CIDECT.

Unfortunately there is a lack of fracture mechanics tests with cold-formed products, so the rules developed in this report are mainly based on other safe-sided procedures.

All contributions and comments received and also the valuable discussions held in ECCS-TC6 to complete this report are gratefully acknowledged.

Aachen, November 2011

Prof. Dr.-Ing. G. Sedlacek

Director of ECCS-Research

Preface

(1) The design rules in EN 1993 for steel structures are based on ductile behaviour of steel that is controlled by the upper-shelf toughness behaviour of steels in the toughness-temperature diagram.

(2) Brittle failure of steels may be possible where

- the shape of the structural components with notches from welds, unacceptable faults like cracks at the critical notches, that may have been overlooked in production tests or tests during inspections, and
- extremely low temperatures, that may reduce the toughness properties and are associated with
- stresses from external loads and internal restraints,

come together and form an accidental fracture mechanical limit state scenario.

(3) EN 1993-1-10 gives rules for the choice of material to avoid brittle fracture of steel structures that are based on a mathematical model calibrated to large-scale tests to obtain sufficient reliability.

(4) This report gives guidance for the use of EN 1993-1-10 for welded structures made of hot-finished or cold-formed hollow sections.

(5) Though EN 1993-1-10 gives rules regarding how to consider cold-forming in the production, for the choice of material these rules are not sufficient for the specific case of cold-formed hollow sections because of the high degrees of cold-forming.

(6) Producers of cold-formed hollow sections have hence requested an urgent supplement to EN 1993-1-10 so that it can be used for both hot-rolled hollow sections and cold-formed hollow sections, and does not provide an obstacle to free marketing.

(7) This report is the result of a common action of CIDECT (Comité International pour le Developpement et l´Étude de la Construction Tubulaire) with experts from CEN/TC250 to prepare rules for the assessment of the appropriate steel quality for structures with cold-formed hollow sections with the use of EN 1993-1-10.

(8) This report could be - in line with Resolution No. 255 agreed at the CEN/TC250-meeting in Malta - a common basis for the maintenance, further harmonisation, further development and promotion of Eurocode 3.

Ispra, November 2010

J.A. Calgaro, U. Kuhlmann, G. Sedlacek CEN/TC250

R. Pope CEN/TC135

P. Ritakallio CIDECT

M. Geradin, A. Pinto JRC

Executive summary

(1) The choice of steel material for welded hollow section structures to avoid brittle fracture at low temperatures requires a study with experiments carried out with test specimens which represent the fracture mechanical behaviour of welded components at low temperatures.

(2) Due to the absence of sufficient tests a conservative approach is presented in this report, whereby the choice of material is made by using Table 2.1 of EN 1993-1-10 with an appropriate temperature shift.

(3) Hot-finished hollow sections to EN 10210 do not require a temperature shift because the toughness properties in the flat area and in the corner area are approximately the same and no cold-forming effects can be observed.

(4) For cold-formed hollow sections to EN 10219 this temperature shift is estimated by two approaches:

1. by determining the cold-forming effects on the basis of the procedure in EN 1993-1-10 for base material delivered according to EN 10025,
2. by analysing the results of Charpy-V-impact tests carried out with cold-formed hollow sections delivered according to EN 10219 taking account of the production of hollow sections and the location of test specimen (flat area, bent area and ageing effects).

(5) The results from the two approaches are rather consistent, hence the rules for considering cold-forming effects according to EN 1993-1-10 can be used with certain assumptions for the effective strain from cold-forming.

(6) For circular cold-formed hollow sections a temperature shift should only be considered for $r_i/t \leq 15$ and a maximum value $\Delta T_{cf} = 20$ K should be taken.

(7) For rectangular cold-formed hollow sections the temperature shift ΔT_{cf} is about 35 K for plate thicknesses $t \leq 16$ mm and $\Delta T_{cf} = 45$ K for plate thicknesses 16 mm $< t \leq 40$ mm.

(8) For using these concepts, Table 2.1 of EN 1993-1-10 has been extended to temperatures -120 °C $\leq T_{Ed} \leq$ 10 °C.

(9) The evaluations of the results of Charpy-V-tests made with cold-formed rectangular hollow-sections reveal a significant influence of the toughness quality of the base material used for cold-forming.

(10) Modern steels (killed steels) exhibit ageing effects which may be neglected, so this effect need not be taken into account.

(11) The toughness quality is in general far better than required by EN 10219. Therefore, instead of using a single value of ΔT_{DCF} for all qualities a differentiation of ΔT_{cf}-values according to the toughness properties measured in the flat areas of the cross sections could be applied. This would result in using toughness classes of the material above the level of the minimum toughness-requirements specified in EN 10219.

Table of contents

List of symbols

Capital

A, B, C	Coefficients for curve fitting of the KV-T-curve.
C^*	Slope of mathematical expression for the KV-T-curve in the temperature-transition range.
DCF [%]	Degree of cold-forming expressed by the plastic strain ε_{pl} applied to a sample. In testing the degree of cold-forming is in general uniformly distributed across the cross section of the sample.
JR, J0, J2 K2, M, N ML, NL	Designations for the toughness quality of steels, see Table 3-1.
KV	Charpy-V-notch impact energy [Joule] determined at a certain temperature T or T_{KV} contributing to a KV-T-curve.
KV_{US}	Upper-shelf value of the Charpy-V-impact energy.
$\overline{\overline{KV}}$	KV-value produced by sub-sized Charpy-V-test specimens.
$\overline{KV}, \overline{KV}_{27J}$	Mathematical parameters using KV, KV_{us} and KV = 27J-values.
S275	Steel grade for structural steel with minimum yield strength 275 N/mm^2, see Table 3-1.
T	Temperature [°C]
T_{27J}	Test temperature [°C] for notch-impact Charpy-V-tests (CNV-tests) to achieve an impact energy of 27J. This value is used as a specification for the material toughness in EN 10025, EN 10210 and EN 10219. Other values, e.g. T_{40J} are in general expressed in terms of T_{27J}.
$T_{27J,bent}$	T_{27J}-value [°C] measured in the corner area of cold-formed sections.
$T_{27J,bent,corr.}$	T_{27J}-value [°C] developed from $T_{27J,bent}$ by correcting it with ΔT_{ss} and $\Delta T_{DCF,pos}$.
$T_{27J,plane}$	T_{27J}-value [°C] measured in the plane area of the cold-formed cross section according to EN 10219.
$T_{27J,plane,corr.}$	T_{27J}-value [°C] developed from $T_{27J,plane}$ by correcting it with ΔT_{ss}, $\Delta T_{DCF,pos}$ and ΔT_{DCF} due to “universal forming” process.

$T_{calc,i}$ — Temperature T [°C] at which fracture occurs in large scale fracture mechanics tests with the test specimen i according to calculation using the calculable limit state equation.

T_{Ed} — Reference temperature [°C] of steel structures for choice of steel material to avoid brittle fracture according to EN 1993-1-10.

T_{Ed} is the minimum temperature of air T_{mv} [°C] (corresponding to a 50 years return period) minus temperature loss by radiation (-5K), when the standardized conditions for the design size of crack at the hot-spot of notched structural components, for neglecting cold-forming effects and strain rate effects and for the reliability of results all specified in EN 1993-1-10 are adopted.

For other conditions, e.g. with additional cold-forming, T_{Ed} can be modified by temperature shifts, e.g. by ΔT_{cf} [K].

T^*_{Ed} — Modified reference temperature [°C] for steel structures for choice of steel material to avoid brittle fracture according to EN 1993-1-10, e.g. from cold-forming effects:

$$T^*_{Ed} = T_{Ed} - \Delta T_{DCF}.$$

$T_{exp,i}$ — Temperature T [°C] at which fracture occurs in large scale fracture mechanics tests with the test specimen i according to measurement.

T_{KV} — Temperature [°C] determined for a certain Charpy-V-notch impact energy KV contributing to a KV-T-curve.

T_{Rd} — Temperature [°C] at which a safe level of fracture toughness can be relied upon under the conditions being evaluated.

T_{US} — Minimum temperature [°C] for reaching the upper-shelf value of Charpy-V-impact energy KV_{us}.

Regular

b — External width of rectangular hollow sections

b_i — Difference between measured and calculated fracture temperature $b_i = T_{exp} - T_{calc}$

c — Notch depth of the Charpy impact specimen

h — Height of hollow section

Thickness of Charpy-specimen

f_y	Yield strength of material as specified in EN 10025, EN 10210 or EN 10219.
m	Mean value
r_a	Outer radius of hollow sections.
r_i	Inner radius of hollow sections.
r_m	Mean radius of hollow sections.
t	Wall thickness of hollow section.
w	Width of Charpy-specimen
z_e	Geometric quantity

Greek symbols

$\Delta\varepsilon$	Difference between effective strain ε_{eff} and strain considering the position of the Charpy-V-Notch specimen ε_{pos}.
$\overline{\Delta T_R}$	Temperature shift [K] between the mean value of b_i and the design fractile m+3.03 σ of the distribution of b_i, that represents the design value for measured input values. In case of EN 1993-1-10: $\Delta\overline{T}_R = +38\,K$.
$\Delta T^*_{R,nom}$	Temperature shift [K] related to mean value of the b_i-distribution to achieve the required reliability of the design equation using nominal values for T_{27J} and f_y. In case of EN 1993-1-10: $\Delta T_R^* = \Delta\Delta\overline{T}_R^* - \Delta T_R = +38K - 45K = -7K$. This value is designated as ΔT_R in EN 1993-1-10 and included in the procedure to determine Table 2.1 of EN 1993-1-10.
ΔT_{cf}	Temperature shift [K] in the notch impact energy-temperature diagram due to cold-forming (cf), also designated as ΔT_{DCF}.
ΔT_{DCF}	See ΔT_{cf}
$\Delta T_{DCF,pos}$	Shift of temperature [K] caused by the position of the test specimen in a bent plate with strain-gradient that is not identical with the position close to the mostly strained surface and so receives only ε_{pos} instead of ε_{pl}.
ΔT_R	Additive safety element [K] in the limit state equation with T_{Ed} (action) and T_{Rd} (resistance), that is determined from the evaluation of large scale fracture mechanics tests and yields the required reliability of the design equation that is underlying Table 2.1 in

EN 1993-1-10.

$\Delta T_{R,meas}$ Temperature shift [K] between mean values of $b_i = (T_{exp,i} - T_{calc,i})$, where $T_{calc,i}$ is determined from measured input values of T_{27J} and f_y.

In case of EN 1993-1-10: $\Delta T_{R,meas} = 0$ K.

ΔT_{ss} Temperature shift [K] due to sub-sized Charpy-V-test-specimens.

$\Delta\Delta T_R$ Temperature shift [K] to take nominal values for T_{27J} and f_y into account instead of measured values.

In case of EN 1993-1-10: $\Delta\Delta T_R = + 45$ K.

ε_{eff} Value of plastic strain equivalent to a DCF-value where the plastic strain distribution is not constant across the critical cross section of the Charpy-V-test specimen.

ε_{pl} Plastic strain also designated as DCF (Degree of Cold-Forming [%]) relevant for the temperature shift ΔT_{DCF} for cold-forming in the Charpy-V-impact energy-temperature diagram.

For applying ΔT_{DCF} the value ε_{pl} is supposed to be equally distributed across the critical cross section of the Charpy-V-test specimen.

ε_{pos} Strain considering the position of the Charpy-V-Notch specimen ε_{pos}.

σ Standard deviation

σ_{Ed} Nominal stress on service level applied from external forces to the structural component, in an accidental design situation according to EN 1993-1-10.

The leading action is the temperature T_{Ed} acting on a structural component with a standardized severe notch situation and the design value of crack at the hot spot of the notch. The external forces are from accompanying actions (permanent loads and frequent values of variable loads without partial factors). σ_{Ed} does not include residual stresses.

Residual stresses are included in the procedure of EN 1993-1-10 by two means:

1. Local residual stresses from welding are included in the evaluation procedure of fracture mechanical large scale tests.
2. Residual stresses from restraints to the weld shrinkage of the component are taken into account by a supplementary nominal stress $\sigma_S = 100$ MPa.

σ_S Residual stresses from restraints to the weld shrinkage of the component.

$\frac{\sigma_{Ed}}{f_y}$	Utilisation rate from external stresses. EN 10025 gives in its Table 2.1 information for admissible plate thickness for various steel grades, temperatures T_{Ed} and for the utilisation rates: 0.25, 0.50 and 0.75.

1 Objective

(1) The design rules for the choice of material to avoid brittle fracture given in EN 1993-1-10 are related to welded structures made by plates and hot rolled profiles and rolled sections delivered acc. to EN 10025.

(2) The main conclusion of this standard is the possibility to make a choice of the base-material for fabrication on the basis of Table 2-1 of EN 1993-1-10, see Table 1-1:

Table 1-1: Maximum permissible values of element thickness in mm

Steel grade	Sub-grade	Charpy energy CVN		Reference temperature T_{Ed} [°C]																				
		at T [°C]	J_{min}	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50
				$\sigma_{Ed} = 0,75\ f_y(t)$							$\sigma_{Ed} = 0,50\ f_y(t)$							$\sigma_{Ed} = 0,25\ f_y(t)$						
S235	JR	20	27	60	50	40	35	30	25	20	90	75	65	55	45	40	35	135	115	100	85	75	65	60
	J0	0	27	90	75	60	50	40	35	30	125	105	90	75	65	55	45	175	155	135	115	100	85	75
	J2	-20	27	125	105	90	75	60	50	40	170	145	125	105	90	75	65	200	200	175	155	135	115	100
S275	JR	20	27	55	45	35	30	25	20	15	80	70	55	50	40	35	30	125	110	95	80	70	60	55
	J0	0	27	75	65	55	45	35	30	25	115	95	80	70	55	50	40	165	145	125	110	95	80	70
	J2	-20	27	110	95	75	65	55	45	35	155	130	115	95	80	70	55	200	190	165	145	125	110	95
	M,N	-20	40	135	110	95	75	65	55	45	180	155	130	115	95	80	70	200	200	190	165	145	125	110
	ML,NL	-50	27	185	160	135	110	95	75	65	200	200	180	155	130	115	95	230	200	200	200	190	165	145
S355	JR	20	27	40	35	25	20	15	15	10	65	55	45	40	30	25	25	110	95	80	70	60	55	45
	J0	0	27	60	50	40	35	25	20	15	95	80	65	55	45	40	30	150	130	110	95	80	70	60
	J2	-20	27	90	75	60	50	40	35	25	135	110	95	80	65	55	45	200	175	150	130	110	95	80
	K2,M,N	-20	40	110	90	75	60	50	40	35	155	135	110	95	80	65	55	200	200	175	150	130	110	95
	ML,NL	-50	27	155	130	110	90	75	60	50	200	180	155	135	110	95	80	210	200	200	200	175	150	130
S420	M,N	-20	40	95	80	65	55	45	35	30	140	120	100	85	70	60	50	200	185	160	140	120	100	85
	ML,NL	-50	27	135	115	95	80	65	55	45	190	165	140	120	100	85	70	200	200	200	185	160	140	120
S460	Q	-20	30	70	60	50	40	30	25	20	110	95	75	65	55	45	35	175	155	130	115	95	80	70
	M,N	-20	40	90	70	60	50	40	30	25	130	110	95	75	65	55	45	200	175	155	130	115	95	80
	QL	-40	30	105	90	70	60	50	40	30	155	130	110	95	75	65	55	200	200	175	155	130	115	95
	ML,NL	-50	27	125	105	90	70	60	50	40	180	155	130	110	95	75	65	200	200	200	175	155	130	115
	QL1	-60	30	150	125	105	90	70	60	50	200	180	155	130	110	95	75	215	200	200	200	175	155	130
S690	Q	0	40	40	30	25	20	15	10	10	65	55	45	35	30	20	20	120	100	85	75	60	50	45
	Q	-20	30	50	40	30	25	20	15	10	80	65	55	45	35	30	20	140	120	100	85	75	60	50
	QL	-20	40	60	50	40	30	25	20	15	95	80	65	55	45	35	30	165	140	120	100	85	75	60
	QL	-40	30	75	60	50	40	30	25	20	115	95	80	65	55	45	35	190	165	140	120	100	85	75
	QL1	-40	40	90	75	60	50	40	30	25	135	115	95	80	65	55	45	200	190	165	140	120	100	85
	QL1	-60	30	110	90	75	60	50	40	30	160	135	115	95	80	65	55	200	200	190	165	140	120	100

(3) This table gives the “admissible” plate thickness depending on the parameters

- steel grade and T_{27J}-value,
- applied temperature T_{Ed} (from + 10 °C to -50 °C),
- utilisation rate σ_{Ed}/f_y for accidental design situations, where σ_{Ed} is the service stress under “frequent” load combination (see EN 1990 – Eurocode – Basis of structural design). **(1-1)**

This table can also be used as a reference table for taking strain-rate-effects $\dot{\varepsilon}$ and effects of cold-forming DCF = ε_{cf} into account by appropriate temperature shifts $T_{Ed}^{*} = T_{Ed} - \Delta T_{\dot{\varepsilon}} - \Delta T_{DCF}$.

(4) The table is based on fracture mechanics using the Master Curve Correlation between Charpy and fracture toughness. T_{27J} is correlated to the temperature T_{100} where 100 MPa·m$^{1/2}$ are reached in fracture toughness tests. T_{27J} cannot be measured directly from the Charpy test with standard

Charpy specimen as presented in Figure 1-1. It must be determined from CV-T-curves by hand or by mathematical curve approximation, but no standardised method is given.

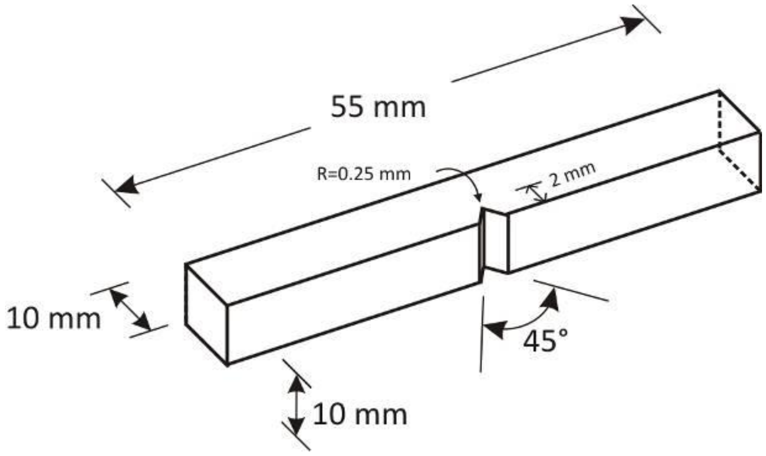


Figure 1-1: Standardised Charpy-V-notch specimen

(5) EN 1993-1-10 also allows to take into account the reduction of toughness from the cold-forming of plates (base material) by the temperature shift (equation 2.2 and 2.4)

$\Delta T_{DCF} = 0$	for	DCF ≤ 2 %	**(1-2)**
$\Delta T_{DCF} = 3\ x\ DCF$	for	2 % < DCF ≤ 10 %	**(1-3)**
$\Delta T_{DCF} = 1{,}5\ x\ DCF$	for	2 % < DCF ≤ 10 % in case of stress-relief by heat- treatment	**(1-4)**

where DCF is the plastic strain (Degree of Cold-Forming).

Note: *The limit DCF ≤ 10 % used in EN 1993-1-10 is safe-sided and has been extended to DCF ≤ 15 % in 2(1) and 6.1-(9)1 of this report because of further test evidence.*

(6) Figure 1-2 shows the justification of this linear relationship and their safe sidedness from tests with various steels and various transition temperatures. For values larger than 10 % see section 2(1).

It can be seen, that cold-forming with a degree DCF = 10 % leads to an increase of the transition temperature of approximately 30 K for all steels.

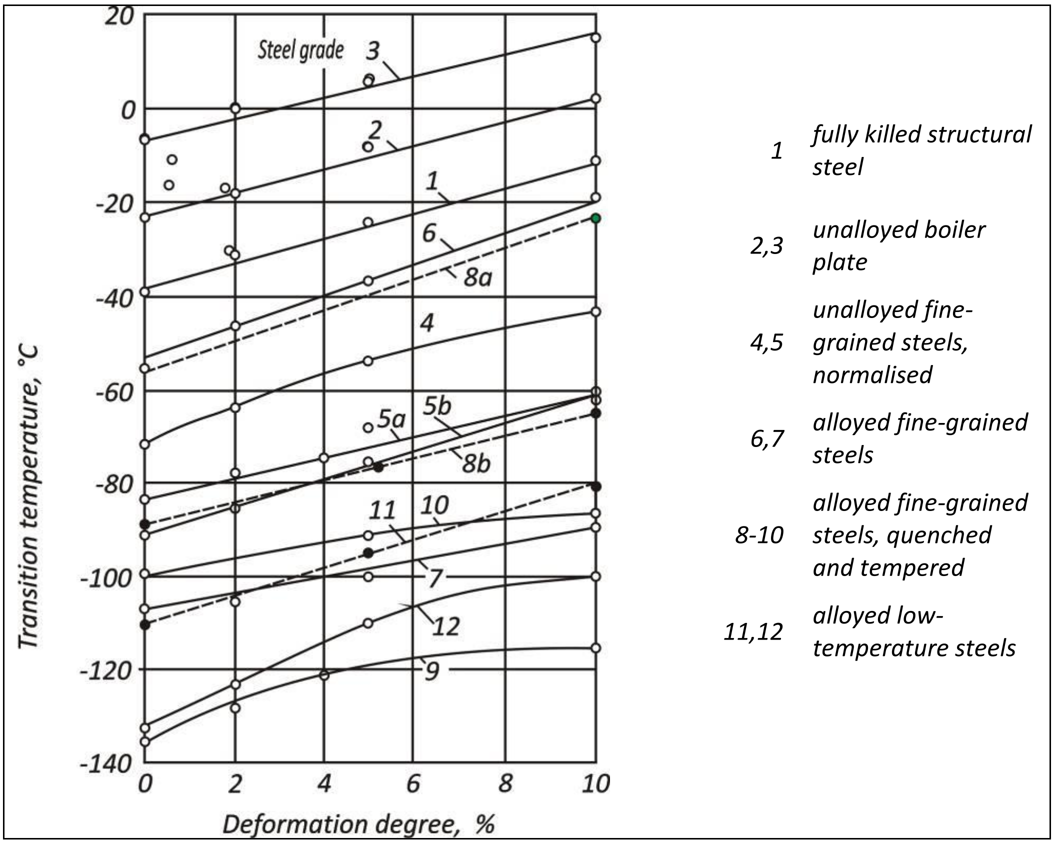


Figure 1-2: Effects of Degree of Cold-Forming (DCF %) on the transition temperature [°C] in the range of DCF = 0 % ÷ 10 % [9]

(7) Table 2.1 in EN 1993-1-10, cf. Table 1-1, is based on a calculable fracture-mechanics-approach, which has been calibrated to tests, to determine the inherent safety element ΔT_R (see equation 2.2 in EN 1993-1-10) in this approach, see Figure 1-3.

(8) Figure 1-3 gives on the abscissa the differences b_i between the temperature $T_{exp,i}$ at which the test specimen i broke in brittle failure and the temperature $T_{calc,i}$ determined from the fracture mechanics model to predict the failure of the test specimen with input from measured material data. The ordinate gives the probability distribution, with m being the mean value (50 % value) and σ being the standard deviation.

The continuous lines give the tangent to the distribution lines (dotted lines) in the design point ($m + 3{,}03 \cdot \sigma$).

Note: The values are based on test specimens of European steel which exceeds the limits T_{27J} and f_y given in EN 10025 considerably.

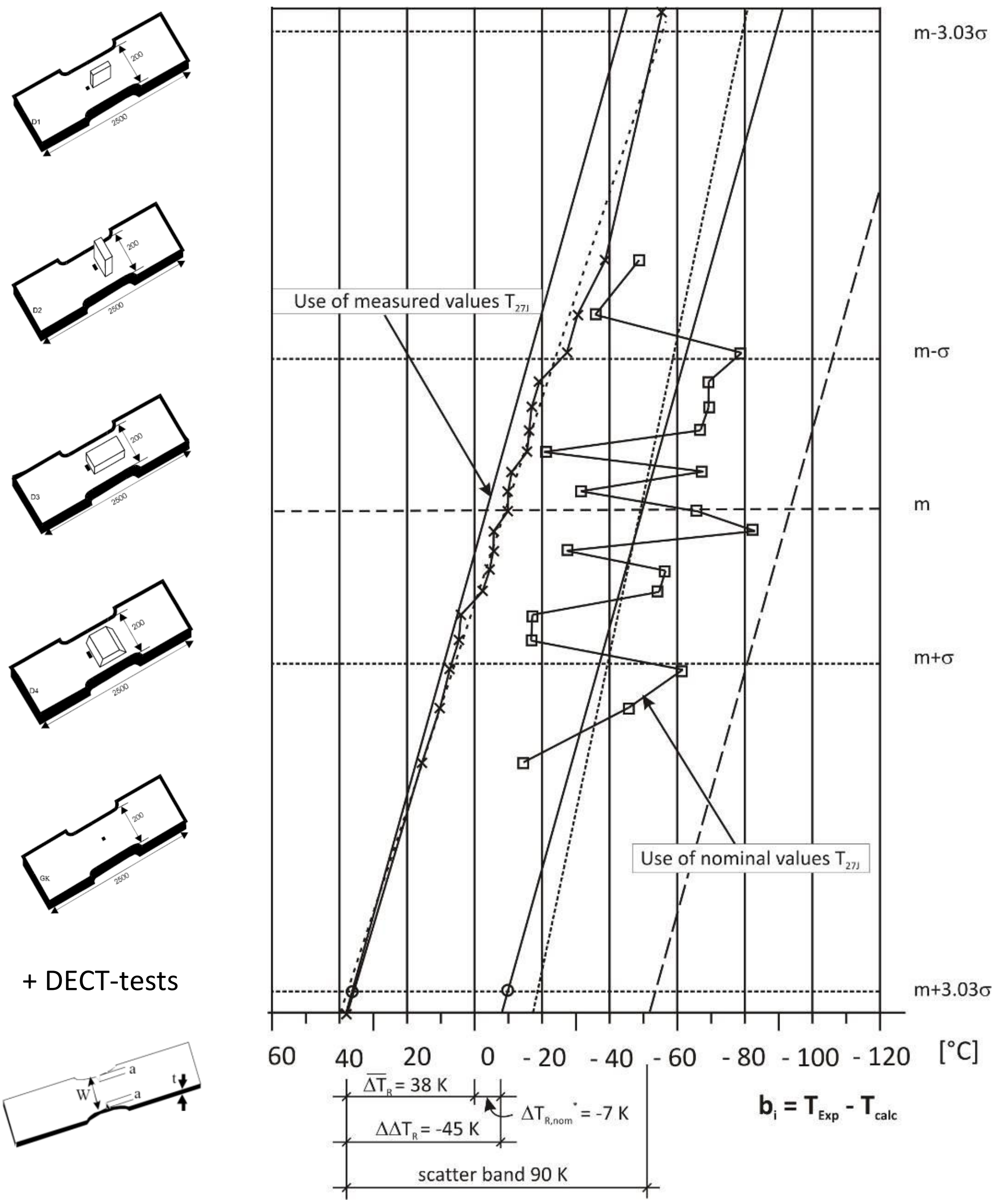


Figure 1-3: Determination of the safety element ΔT_R for DECT-elements

(9) Apparently the calculable values and experimental values fit well, so that the tangent to the distribution line nearly hits the point (b = 0, m). Hence for measured material data the calculable model can be used with the safety element $\Delta T_{R,meas} = 0$ to determine expected (mean) values of temperature for fracture.

(10) In case the design values shall be determined from measured material data, the fractile m + 3.03·σ is relevant, for which a temperature shift of $\Delta \overline{T}_R = +38K$ is necessary.

(11) If the material data from material standards are used (nominal f_y-values and T_{27J}-values), e.g. from EN 10025, the evaluation shows that the scatter band

of deviations from nominal values is in the range of ≈ 90 K. Therefore the reference to nominal values from material standards instead of reference to measured values requires a temperature shift of about $\Delta\Delta T_R$ = - 45 K, which is half the width of the scatter band.

(12) Hence $\Delta T^*_{R,nom} = \Delta\Delta T_R - \Delta\bar{T}_R$ = -45 K + 38 K = - 7 K is the value of the temperature shift, to predict design values of test results for nominal material data specified in the material standard EN 10025.

(13) Hence the difference of toughness between measured toughness-values and toughness values specified in EN 10025 is in the range of $\Delta\Delta T_R$ = -45 K.

Table 2.1 in EN 1993-1-10 has been determined such that the safety element $\Delta T^*_{R,nom}$ = -7 K is included, so that the scale for T_{Ed} starts with T_{Ed} = 0 °C.

(14) The purpose of this report is to give data for the choice of material to avoid brittle fracture for hollow section profiles produced to the standards EN 10210 and EN 10219 on the basis of the background information to EN 1993-1-10 given above.

Note: Further background information can be taken from the JRC-Scientific and Technical Report [1], the thesis of Kühn [2]or Stranghöner [3]:

Commentary and worked examples to EN 1993-1-10 "Material toughness and through thickness properties and other toughness oriented rules in EN 1993" - EUR 23510-2008 that can be downloaded from *http://eurocodes.jrc.ec.europa.eu/showpublication.php?id=134*

Bertram Kühn: Beitrag zur Vereinheitlichung der europäischen Regelungen zur Vermeidung von Sprödbruch. Schriftenreihe Stahlbau-RWTH Aachen, Heft 54, Aachen 2005, Shaker Verlag, ISBN: 3-8322-3901-4, ISSN: 0722-1037

Stranghöner, N.: Werkstoffauswahl im Stahlbrückenbau. Forschungsbericht 4/2006, Herausgeber: Deutscher Ausschuss für Stahlbau DASt, Düsseldorf, Stahlbau Verlags- und Service GmbH, 2006, ISBN 978-3-923726-20-2.

2 Extension of the method in EN 1993-1-10 to cope with cold-formed sections

(1) The method in EN 1993-1-10 to cope for effects of cold-forming is limited to the following:

1. The linear relationship of the equations (1-3) and (1-4), which in general only applies to DCF-values below a limit DCF_{max} with 10 % ≤ % DCF_{max} ≤ 15 %, depends on the steel grade but is has not been defined for other steels than S355.

   For steels S355 with $f_u/f_y \approx 1,50$ Figure 2-1 gives the change of notch impact energy by cold-forming, that is by increasing dislocation density. The evaluation of the values in Figure 2-1 is given in Figure 2-2 for KV = 27 J and KV = 40 J. Figure 2-1 and Figure 2-2 show that no significant change of T_{27J} or T_{40J} occurs for S355 with increasing degree of cold-forming higher than 15 %. Furthermore the linear decrease of the T_{27J}- and T_{40J}-temperatures is obviously for DCF between 0 % and 15 %.

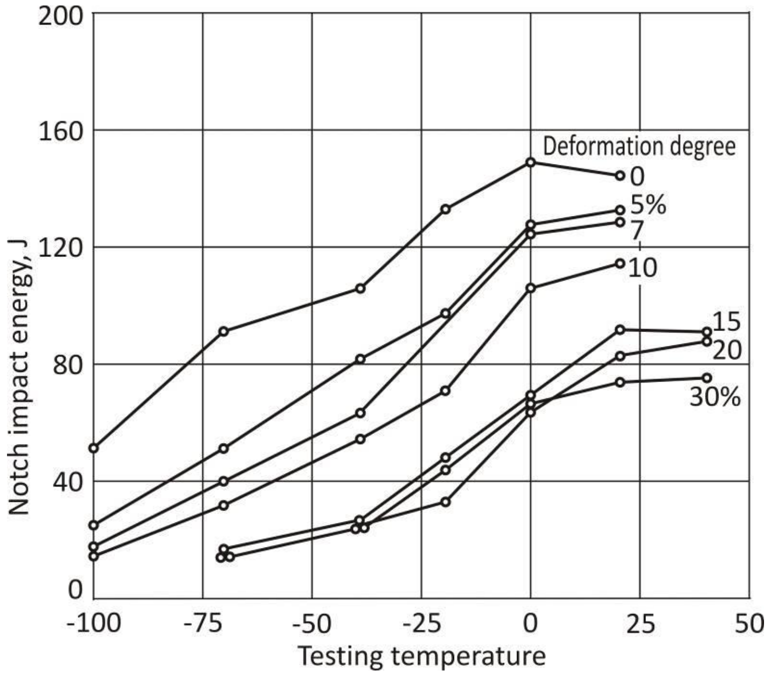


Figure 2-1: Change of notch impact energy by cold-forming for S355J2 [9]

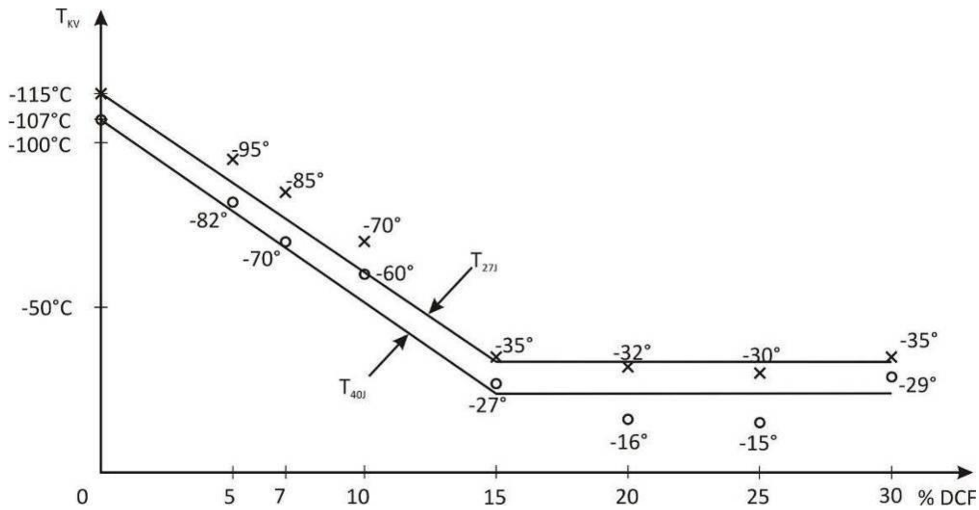
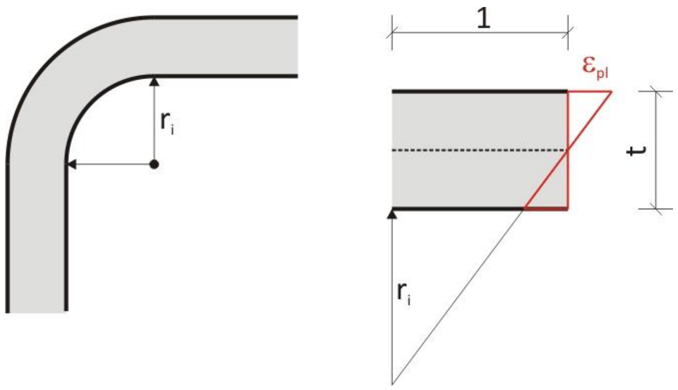


Figure 2-2: Change of T_{27J} and T_{40J}-values by cold-forming for S355J2

2. The validity of the Master Curve Concept which has been determined for standard Charpy-V-test-samples with a cross section 10 mm x w with w = 10 mm, see Figure 1-1, to which the assessment method refers.
3. The assumption of equal distribution of degree of cold-forming across the cross section of the test specimen, which applies to formula (2.2) and (2.4) in EN 1993-1-10.

   In the case of cold-forming by bending the strain distribution varies over the cross section, see estimate in Figure 2-3, and may contain areas with strains from tension and compression.



$$\frac{2\cdot\varepsilon_{pl}}{t} = \frac{1}{r_i + \frac{t}{2}}$$

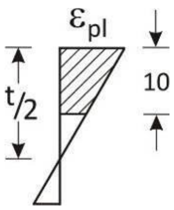
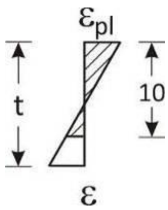
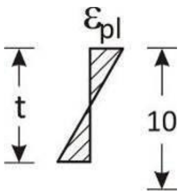
$$\varepsilon_{pl} = \frac{t}{2r_i + t}$$

Figure 2-3: Geometrical definition of ε_{pl}

(2) It is assumed that

- strains from tension and compression have equal effects with regard to the increase of dislocation density,
- the effect of unequal strain-distribution over the critical cross section of the sample for notch impact tests is equivalent with the effect of the mean strain-value of that distribution, see Table 2-1.

Table 2-1: Derivation of ε_{eff}

t [mm]	ε-distribution	ε_{eff}
≥ 20		$\varepsilon_{pl}\left(1-\frac{10}{t}\right)$
< 20 ≥ 10		$\frac{\varepsilon_{pl}}{2}\left\{\frac{t}{20}+\frac{(20-t)^2}{20t}\right\}$
< 10		$\frac{\varepsilon_{pl}}{2}\cdot\frac{t}{10}$

3 Basic approach to determine admissible plate thicknesses for hollow section structures

(1) Hollow section profiles are construction products manufactured according to EN 10210 for hot-finished structural hollow sections and EN 10219 for cold-formed welded structural hollow sections, so that EN 10025 does not apply to these products. Table 2.1 in EN 1993-1-10 has however been prepared for products according to EN 10025.

(2) The toughness-values specified in EN 10210 and EN 10219 for the “semi-finished” products after hot-rolling or cold-forming and welding are given in Table 3-1 together with the values from EN 10025. Furthermore the maximum plate thicknesses produced are given for hot-finished and cold-formed hollow sections according to EN 10210 and EN 10219.

Table 3-1: Required toughness values for steel grades acc. to EN 10025, EN 10210 and EN 10219 and maximum material thicknesses acc. to EN 10210 and EN 10219

required toughness values CVN according to EN 10025, EN10210, EN 10219				maximum material thickness t			
				EN 10210		EN 10219	
type of steel		impact toughness CVN					
steel type	steel grade	T [°C]	J_{min}	steel grade	max. t	steel grade	max t
S235	JR	20	27	JRH	120	JRH	40
	J0	0	27	-	-	-	-
	J2	-20	27	-	-	-	-
S275	JR	20	27	-	-	-	-
	J0	0	27	J0H	120	J0H	40
	J2	-20	27	J2H	120	J2H	40
	K2, M, N	-20	40	NH	65	MH, NH	40
	ML, NL	-50	27	NLH	65	MLH, NLH	40
S355	JR	20	27	-	-	-	-
	J0	0	27	J0H	120	J0H	40
	J2	-20	27	J2H	120	J2H	40
	K, M, N	-20	40	K2H/NH	120/65	K2H, MH, NH	40
	ML, NL	-50	27	NLH	65	MLH, NLH	40
S420	M, N	-20	40	NH	65	MH	40
	ML, NL	-50	27	NLH	65	MLH	40
S460	Q	-20	30	-	-	-	-
	M, N	-20	40	NH	65	MN, NH	40
	QL	-40	30	-	-	-	-
	ML, NL	-50	27	NLH	65	MLH, NLH	40
	QL1	-60	30	-	-	-	-
S690	Q	0	40				
	Q	-20	30				
	QL	-20	40				
	QL	-40	30				
	QL1	-40	40				
	QL1	-60	30				

(3) It is apparent that the minimum toughness values specified in EN 10210 and EN 10219 are identical with the values in EN 10025.

(4) There are however differences in the magnitudes and distribution of toughness properties across the perimeter of the cross section in EN 10210 and EN 10219 as follows:

- EN 10210 guarantees the specified values along the whole perimeter of the cross section for both circular and rectangular sections. This can be certified according to EN 10210-1 section 5.2 - options under item 1.9 by specific tests.
- EN 10219 guarantees the specified values along the whole perimeter of the cross section for circular sections and in the flat part of rectangular sections. Tests in the cold-formed (radius-area) are not provided in EN 10219-1 section 5.2 - options.

(5) Therefore Table 2.1 of EN 1993-1-10 may be directly applied for hot-finished hollow profiles according to EN 10210 with the following assumptions:

- the hot-rolling process is performed with a temperature-regime that excludes “cold-forming effects”,
- the mean values of the statistical distributions of the toughness values measured in the relevant formed areas of the cross sections are at least 45 K higher than the values specified in the product standards to obtain the same conditions for ΔT_R as those used in EN 1993-1-10, see Figure 1-3.

(6) For hot-finished hollow sections the evaluation of tests as documented in Annex A.4 is performed in section 11 of this report and confirms that this condition is fulfilled.

(7) For cold-formed sections it is necessary to have a deeper look into magnitudes and distributions of material properties of the products as EN 10219 does not sufficiently specify the material properties to determine admissible plate thicknesses.

4 Approaches to determine admissible plate thicknesses for cold-formed hollow sections

4.1 Production methods and feed-material

(1) Rectangular and square tubes in general are produced from hot-rolled strip by continuous roll-forming in combination with electric welding or submerged arc welding. Plates are used in specific situations only.

(2) There are two different processes for the production:

1. “Direct forming”

For circular cross sections the properties of the roll-formed and welded product are influenced by the degree of cold-forming.

For rectangular cross sections the hot-roll strip is roll-formed directly to the desired rectangular cross section.

In this case the flat face of the cold-formed rectangular section has about the same properties as the feed material.

For the production of rectangular cross sections this process is used by the minority of producers.

2. “Universal forming”

The roll-forming of hot-rolled strip to rectangular cross sections involves two steps:

- forming and welding of a round tube with equivalent diameter, see “direct forming”,
- forming/shaping the round tube to the desired rectangular cross section.

In this case the degree of cold-forming at the flat face is roughly 2 x the degree of cold-forming for the equivalent round tube.

The process is used by the majority of producers.

(3) Plates produced with rolling reversals are delivered to EN 10025.

(4) Hot rolled strips may be delivered to EN 10025, EN 10111 or EN 10149.

(5) In the following it is assumed, that

1. The metallurgical properties of feed-steels to EN 10025 apply, so that methods in EN 1993-1-10 explained in section 1, 2 and 3 of this report may be used to derive the toughness-properties of cold-formed sections from that of the feed material by following the production process.
2. For circular sections “direct forming” is applied.
3. For rectangular sections “universal forming” is applied.

4.2 Approaches

(1) The most efficient way to determine the effects of cold-forming in cold-formed hollow sections finished to EN 10219 would be to perform fracture mechanics tests with welded large scale test specimens and to follow the procedure as carried out in EN 1993-1-10 to determine a specific list of maximum permissible values of element thickness for welded hollow section structures similar to the one in Table 1-1.

(2) Due to the absence of such specific fracture mechanics tests with components made of cold-formed sections the following approximation is applied:

1. The fracture mechanics tests carried out for flat material according to EN 10025 are considered to be applicable also to welded hollow section structures, see Figure 1-3.

   In consequence the distribution line

   $b_i = T_{exp} - T_{cal}$

   with the mean value

   $b_m = 0$

   and the temperature shift

   $\Delta T_R = 38\ K$

   to determine the design value b_d is taken as a basis for the further evaluations.

2. Therefore the specific questions related to the applicability of Table 1-1 to cold-formed sections are the following:

   1. Is the statistics of differences between the measured material data T_{27J} and the nominal values T_{27J} as specified in EN 10219 different to the statistics related to the values in EN 10025, in other words: does $\Delta\Delta T_R$ = -45 K also apply to material according to EN 10219 that give the safety element ΔT_R = -7 K.

   2. Is it necessary to apply the temperature shift

      $\Delta T_{DCF} = -3 \cdot \varepsilon_{cf}$

      or is the temperature shift ΔT_{DCF} already included in the difference $\Delta\Delta T_R$ determined by testing the material properties of the finished cold-formed profiles, which include already all effects of cold-forming.

(3) To find the solutions to these questions two approaches are applied:

Approach no. 1: This approach does not consider any material testing of cold-formed sections and treats cold-formed sections as a product fabricated from EN 10025-material.

$\Delta\Delta T_R$ = -45 K and $\Delta T_{DCF} = -3\cdot\varepsilon_{cf}$ are applied together with the concept of effective strains according to section 2 to consider the various steps of the production process.

The conservative results of approach no. 1 are applicable to any size of hollow section and any feed material.

They also apply to any cold-formed cross-section, e.g. as designed according to EN 1993-1-3.

Approach no. 2: This approach takes profit of the result of material testing with cold-formed sections that are listed in Annex A. The evaluation is intended to develop a relationship between the measured T_{27J}-values at the critical corners, where the maximum plastic strain effects occur and the nominal values of T_{27J} in the flat face of the cross-sections as specified in EN 10219. Such a relationship would yield a specific $\overline{\Delta\Delta T_R}$ -value for cold-formed sections, that could be compared with $\Delta\Delta T_R$ = -45 K to identify the shift ΔT_{DCF} necessary to apply Table 1-1.

The problem is however that the T_{27J}-values as measured cannot be directly used for determining ΔT_{DCF} because of the following reasons:

1. The data measured in the corner region and in the flat face region all contain a certain amount of cold-forming. As only the difference of measured data between these regions can be identified, the absolute values can only be determined from corrections of the measured values using the temperature shift model in EN 1993-1-10.
2. The measured data need corrections for
   - the strain gradient across the wall thickness,
   - a possible favourable position of the CVN-test specimens in the wall,
   - the triaxiality of stress-state, where the dimensions of the CVN-test specimens are not the standard dimensions.
3. Also for these corrections the temperature shift model in EN 1993-1-10 is used.

(4) In conclusion approach no. 1 and approach no. 2 are not fully independent, as approach no. 2 uses the shift model from approach no. 1 to make the measured data in approach no. 2 consistent with the procedure in EN 1993-1-10.

5 Cold-formed circular hollow sections

5.1 Approach no. 1

(1) For cold-formed circular hollow sections made of plates according to EN 10025 with t ≥ 11 mm, which corresponds to t = 10 mm for test sample and 2 x 0,5 mm for machining, the maximum plastic strain ε_{pl} is given by

$$\varepsilon_{pl} = \frac{1}{1 + 2\frac{r_i}{t}} \qquad \textbf{(5-1)}$$

where

r_i is the inner radius,

t is the plate thickness.

(2) A first rough estimate with the criterion given in EN 1993-1-10

$\varepsilon_{pl} \leq 2$ %

for neglecting any cold-forming effects yields the limit

$$\frac{r_i}{t} \geq 0{,}5 \cdot \left(\frac{1}{\varepsilon_{pl}} - 1 \right) = 0{,}5 \cdot \left(\frac{1}{0{,}02} - 1 \right) \approx 25 \qquad \textbf{(5-2)}$$

(3) In this case and where plates or hot rolled strips according to EN 10025 are used for cold-forming, Table 2.1 of EN 1993-1-10 may be used without modifications.

(4) More accurate limits are determined considering the combination of formula (5-3).

$$\varepsilon_{pl} = \frac{1}{1 + 2\frac{r_i}{t}} \qquad \textbf{(5-3)}$$

and ε_{eff} according to Table 2-1.

The resulting values ε_{pl} and ε_{eff} are given in Table 5-1 and Table 5-2.

Table 5-1: ε_{pl}-values from cold-forming to circular tubes

$$\varepsilon_{pl} = \frac{1}{\frac{2r_i}{t} + 1}$$

r_i/t	t [mm] 6	10	16	20	30	40
5	9.09 %	9.09 %	9.09 %	9.09 %	9.09 %	9.09 %
10	4.76 %	4.76 %	4.76 %	4.76 %	4.76 %	4.76 %
15	3.23 %	3.23 %	3.23 %	3.23 %	3.23 %	3.23 %
20	2.44 %	2.44 %	2.44 %	2.44 %	2.44 %	2.44 %
25	1.96 %	1.96 %	1.96 %	1.96 %	1.96 %	1.96 %
30	1.64 %	1.64 %	1.64 %	1.64 %	1.64 %	**30**
50	0.99 %	0.99 %	0.99 %	0.99 %	**41**	
100	0.50 %	0.50 %	**77**	**61**		
150	0.33 %	**124**				
200	0.33 %					
	208					

Limits from EN 10219: $(r_i/t) \cdot t + t = r_a \leq 1250$ mm

Table 5-2: ε_{eff}-values from cold-forming to circular tubes

ε_{eff} [%], see Table 2-1

r_i/t	t [mm] 6	10	16	20	30	40
5	2.73 %	4.55 %	3.86 %	4.55 %	6.06 %	6.82 %
10	1.43 %	2.38 %	2.02 %	2.38 %	3.17 %	3.57 %
15	0.97 %	1.61 %	1.37 %	1.61 %	2.15 %	2.42 %
20	0.73 %	1.22 %	1.04 %	1.22 %	1.63 %	1.83 %
25	0.59 %	0.98 %	0.83 %	0.98 %	1.31 %	1.47 %
30	0.49 %	0.82 %	0.70 %	0.82 %	1.09 %	**30**
50	0.30 %	0.50 %	0.42 %	0.50 %	**41**	
100	0.15 %	0.25 %	**77**	**61**		
150	0.10 %	**124**				
200	0.07 %					
	208					

Limits from EN 10219: $(r_i/t) \cdot t + t = r_a \leq 1250$ mm

(5) Figure 5-1 shows the lines with equal effective strains ε_{eff} depending on r_i/t and t.

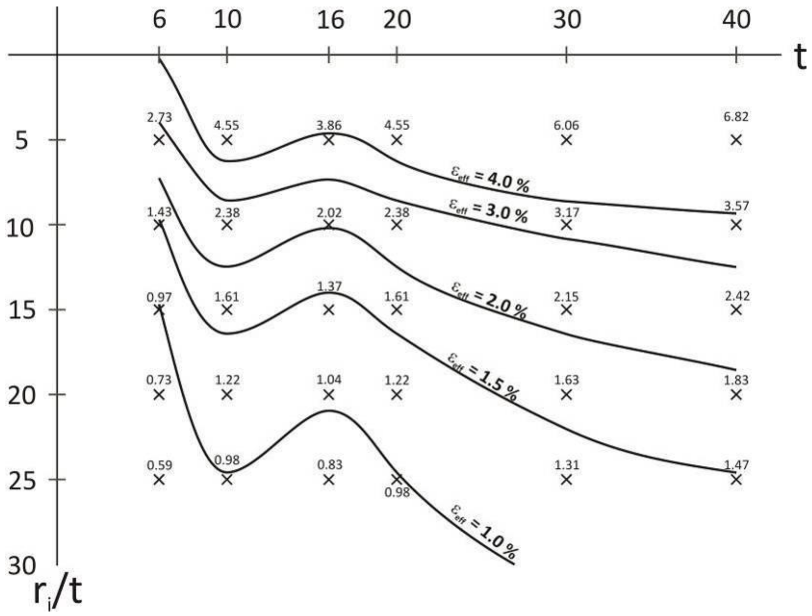


Figure 5-1: ε_{eff}-values [%] at lines of equal effective strains ε_{eff} in dependency on r_i/t and t

(6) Table 5-3 summarizes the effective strains and the resulting temperature shifts ΔT_{DCF} calculated using the formulas (1-2) and (1-3) for various material thicknesses t and r_i/t-ratios. Stress relief by heat-treatment is not considered. The limit $r_a \leq 1250$ mm regarding the outer radius is taken into account.

Table 5-3: Temperature shift ΔT_{DCF} for different r_i/t-ratios and t; for $\varepsilon_{eff} \leq 2$ % cold-forming effects may be neglected (ΔT_{DCF} = 0 K)

r_i/t \ t		**6**	**10**	**16**	**20**	**30**	**40**
5	ε_{eff}	2,73 %	4,55 %	3,86 %	4,55 %	6,06 %	6,82 %
	ΔT_{DCF}	8 K	14 K	12 K	14 K	18 K	20 K
10	ε_{eff}	< 2 %	2,38 %	2,02 %	2,38 %	3,17 %	3,57 %
	ΔT_{DCF}	0 K	7 K	6 K	7 K	10 K	11 K
15	ε_{eff}	< 2 %	< 2 %	< 2 %	< 2 %	2,15 %	2,42 %
	ΔT_{DCF}	0 K	0 K	0 K	0 K	6 K	7 K
20	ε_{eff}	< 2 %	< 2 %	< 2 %	< 2 %	< 2 %	< 2 %
	ΔT_{DCF}	0 K	0 K	0 K	0 K	0 K	0 K
25	ε_{eff}	< 2 %	< 2 %	< 2 %	< 2 %	< 2 %	< 2 %
	ΔT_{DCF}	0 K	0 K	0 K	0 K	0 K	0 K
30	ε_{eff}	< 2 %	< 2 %	< 2 %	< 2 %	< 2 %	**30**
	ΔT_{DCF}	0 K	0 K	0 K	0 K	0 K	
50	ε_{eff}	< 2 %	< 2 %	< 2 %	< 2 %	**41**	
	ΔT_{DCF}	0 K	0 K	0 K	0 K		
100	ε_{eff}	< 2 %	< 2 %	**77**	**61**		
	ΔT_{DCF}	0 K	0 K				
150	ε_{eff}	< 2 %	**124**				
	ΔT_{DCF}	0 K					
200	ε_{eff}	< 2 %					
	ΔT_{DCF}	0 K					
		208					

Limits from EN 10219: $(r_i/t) \cdot t + t = r_a \leq 1250$ mm

(7) The values in Table 5-3 demonstrate that the ΔT_{DCF}-values from $\Delta T_{DCF} = -3 \cdot \varepsilon_{eff}$ [K] applicable for $\varepsilon_{eff} > 2$ % only, take values in the range of 6 K to 20 K depending on the plate thickness t and the ratio r_i/t (≤ 15). For more slender cross sections cold-forming effects may be neglected.

5.2 Approach no. 2

(1) Approach no. 2 has not been applied for circular hollow sections due to lack of available CNV-data from measurements at the ready made finished tubes.

6 Cold-formed rectangular hollow sections

6.1 Approach no. 1

(1) For cold-formed rectangular hollow-sections the correction factors ΔT_{DCF} represent corrections from the feed-material/hot rolled strip to the toughness properties in the plane area and the curved area of the cross section.

(2) For the plane area the equivalent diameter r_m of square sections with the depth b gives:

$$4\,b = 2\,r_m \cdot \pi$$

$$r_m = \frac{4b}{2\pi} = \frac{2b}{\pi}$$

$$r_i = r_m - \frac{t}{2}$$

$$= \frac{2b}{\pi} - \frac{t}{2}$$

$$\frac{r_i}{t} = \left(\frac{2}{\pi}\right)\frac{b}{t} - \frac{1}{2} \qquad \textbf{(6-1)}$$

(3) The cold-forming process in the plane area gives a strain-time history as given in Figure 6-1 that produces a strain, see Table 5-2.

$$\sum \varepsilon_{eff} = \sum \left|\varepsilon_{eff}\right| = 2\,\varepsilon_{eff} \qquad \textbf{(6-2)}$$

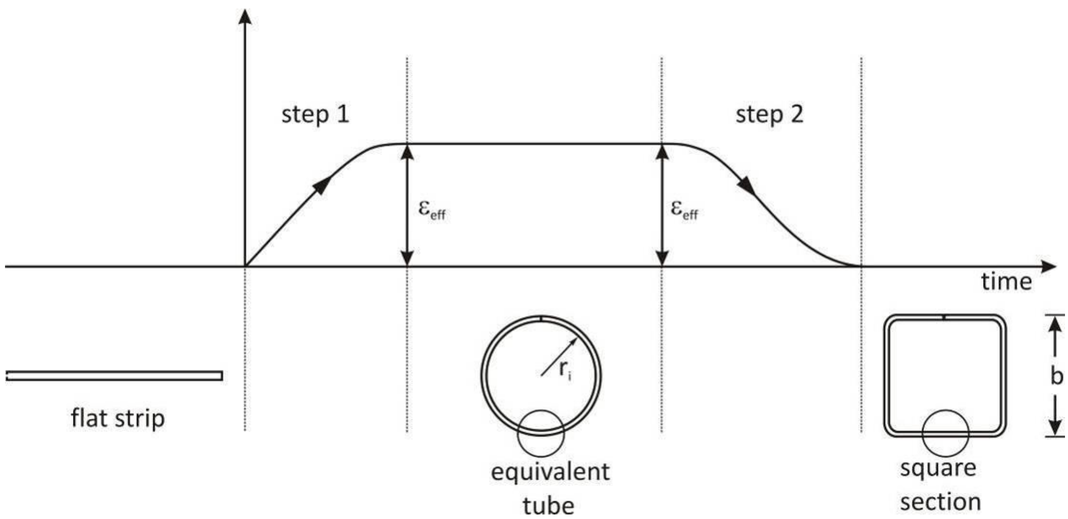


Figure 6-1: Steps of cold-forming at the flat parts of cross section in the "universal forming" process

(4) Table 6-1 gives the effective values $\Sigma\varepsilon_{eff}$ and the associated ΔT_{DCF}-values for the plane area:

Table 6-1: ΔT_{DCF}-values for the flat face of rectangular hollow sections produced to "universal forming" (= 2 x values of Table 5-2)

$\frac{r_i}{t}$	t [mm]					
	6	10	16	20	30	40
5	5,46 % 16 K	9,10 % 27 K	7,72 % 22 K	9,10 % 27 K	12,12 % 36 K	13,6 % 41 K
10	2,86 % 9 K	4,76 % 14 K	4,04 % 12 K	4,76 % 14 K	6,34 % 19 K	7,14 % 21 K
15	1,94 % 6 K	3,22 % 10 K	2,74 % 8 K	3,22 % 7 K	4,30 % 13 K	4,84 % 12 K
20	1,46 % 4,5 K	2,44 % 8 K	2,08 % 6 K	2,44 % 8 K	3,26 % 10 K	3,66 % 11 K
25	1,18 % 3,6 K	1,96 % 6 K	1,66 % 5 K	1,96 % 6 K	2,62 % 8 K	2,94 % 9 K
30	0,98 % 3 K	1,64 % 5 K	1,40 % 4 K	1,64 % 5 K	2,18 % 7 K	
50	0,60 % 2 K	1,00 % 3 K	0,84 % 3 K	1,00 % 3 K		
100	0,30 % 1 K	0,50 % 2 K				
150	0,20 % 1 K					
200	0,14 % 1 K					

(5) The ΔT_{DCF}-values given in Table 6-1 are presented here though they are in general not relevant as the corner area will give the maximum values. These values are further used in section 7.4.4.

(6) The cold-forming process in the corner area gives a strain-time history as given in Figure 6-2.

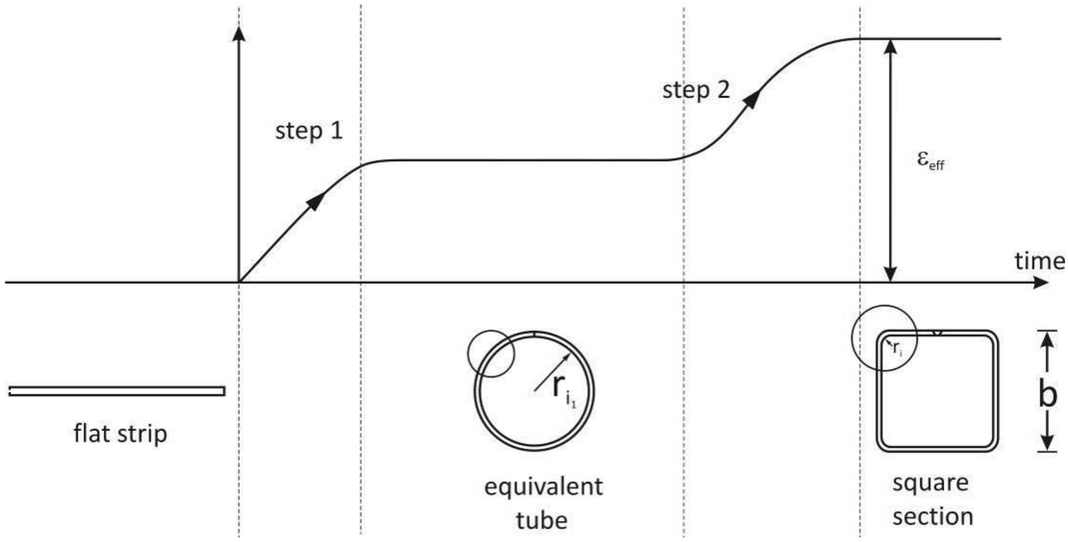


Figure 6-2: **Steps of cold-forming in the corner parts of cross section produced to the "universal forming" process**

(7) The effective strain in the corner area from "universal forming" is accumulated from 2 steps and has the same amount as from "direct forming".

(8) With the relationship of inner radius r_i and the plate thickness t for corners according to EN 10219, B3, the maximum ε_{pl}-values at the surface can be determined according to Table 6-2.

Table 6-2: **ε_{pl} according to EN 10219**

t	**r_i**	**ε_{pl}**	**ε_{pl}** (see Figure 2-3)
t ≤ 6 mm	1,0·t	$\frac{t}{2t+t}$	$\frac{t}{3t} = 33{,}3\%$
6 mm < t ≤ 10 mm	1,5·t	$\frac{t}{3t+t}$	$\frac{t}{4t} = 25{,}0\%$
t > 10 mm	2,0·t	$\frac{t}{4t+t}$	$\frac{t}{5t} = 20{,}0\%$

(9) With the assumptions made in Section 2:

1. The effects of tensile strain and compression strain are identical.
2. Effective strains are the mean values of the distribution of strains along the depth of the Charpy-V-sample used for testing, see Figure 6-3.

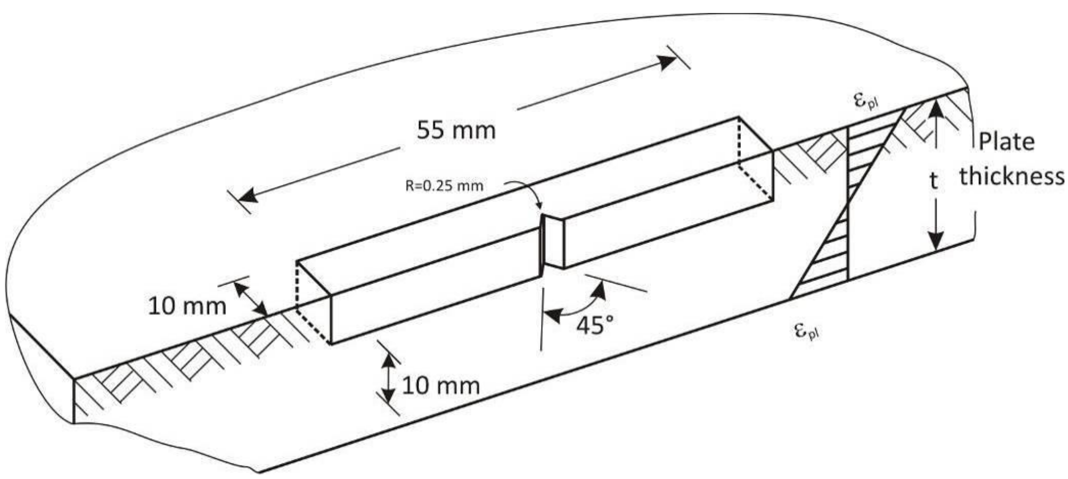


Figure 6-3: Definition of strains along the depth of the Charpy-V-sample

3. The linear relationship of formula (2.4) in EN 1993-1-10 is limited to DCF ≤ 15 %, see Figure 2-2.
4. Ageing effects are rather small for modern killed steels and are in the following included in the cold-forming effects, see Figure 6-4.

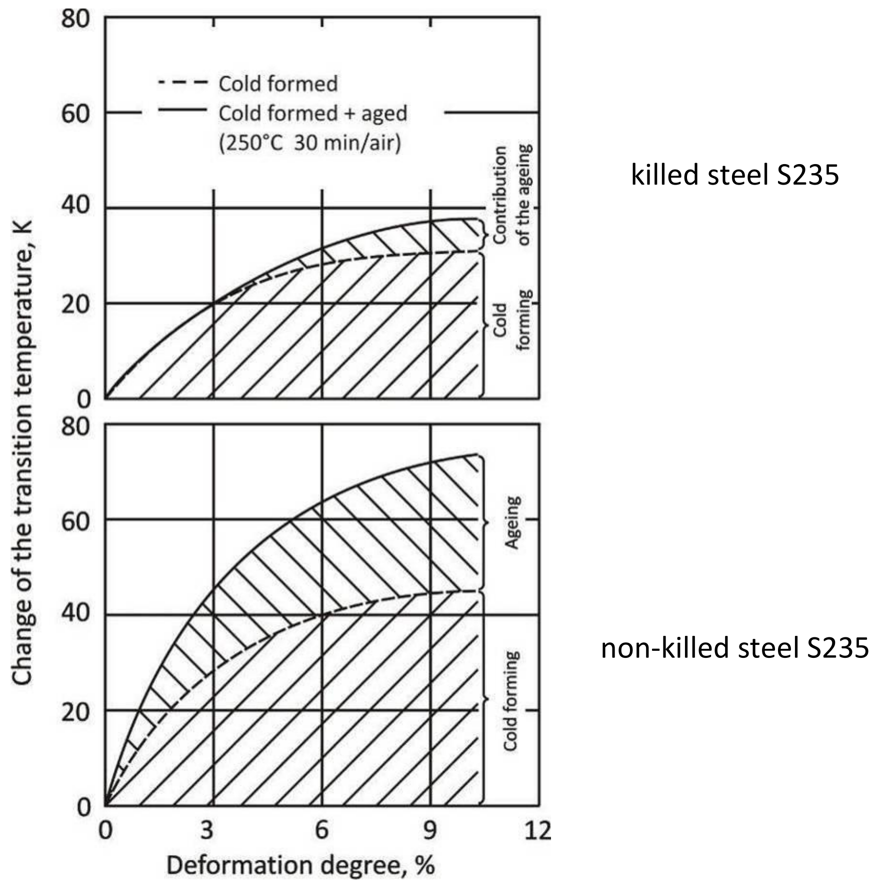


Figure 6-4: Ageing effects of rolled steels [9]

5. Cold-forming effects may be regarded basically as independent on the direction of stress and strain (longitudinal or transversal) as cold-forming effects increase the dislocation density for a given steel volume.

Note: *Though several test results on finished RHS show that for the EN 10219 steel grades, there may be a shift of the toughness-temperature curve to higher temperatures for the transverse direction in comparison to the longitudinal direction, this effect is not considered as it is not important according to the data given in Annex A.*

The effective strains may be determined with the definitions in Table 2-1 as given in Table 6-3. The temperature shifts ΔT_{DCF} are calculated using formula (1-3) and give T_{Ed}^{*} -values, which in relation to Table 1-1 exceed the temperature T_{Ed} = - 50 °C.

Table 6-3: Effective plastic ε_{eff} strains and corresponding ΔT_{DCF} for nominal radii in corner regions

t	ε_{pl}	ε_{eff}	ΔT_{DCF}
t ≤ 6 mm	33,3 %	10 % for *t* = 6 mm	30 K
6 mm < t ≤ 10 mm	25 %	10 % for *t* = 8 mm	30 K
6 mm < t ≤ 10 mm	25 %	12,5 % for *t* = 10 mm	37,5 K
t > 10 mm	20 %	8,7 % for *t* = 12 mm	26 K
t > 10 mm	20 %	10 % for *t* = 20 mm	30 K
t > 10 mm	20 %	15 % for *t* = 40 mm	45 K

(10) Where the production of hollow sections is based on lower bound values for the radii r_i, t from exploiting tolerances, Table 6-4 applies instead of Table 6-2:

Table 6-4: ε_{pl} according to minimum r_i-values from exploiting tolerances

t	r_i	ε_{pl}
t ≤ 6 mm	0,6 t	45,5 %
6 mm < t ≤ 10 mm	t	33,3 %
t > 10 mm	1,4 t	26,3 %

(11) In this case the conclusions for effective plastic strains and the corresponding ΔT_{DCF} are as given in Table 6-5:

Table 6-5: Effective plastic strains ε_{eff} and corresponding ΔT_{DCF} for minimum radii r_i (including tolerances) in corner regions

t	ε_{pl}	ε_{eff}	ΔT_{DCF}
t ≤ 6 mm	45,5 %	13,4 % for *t* = 6 mm	40 K
6 mm < t ≤ 10 mm	33,3 %	13,4 % for *t* = 8 mm	40 K
6 mm < t ≤ 10 mm	33,3 %	16,7 % for *t* = 10 mm	45 K
t > 10 mm	26,3 %	11,5 % for *t* = 12 mm	35 K
t > 10 mm	26,3 %	13,2 % for *t* = 20 mm	40 K
t > 10 mm	26,3 %	15 % for *t* = 24 mm	45 K
t > 10 mm	26,3 %	19,7 % for *t* = 40 mm	45 K

(12) The final conclusions for ΔT_{DCF} are given in Figure 6-5.

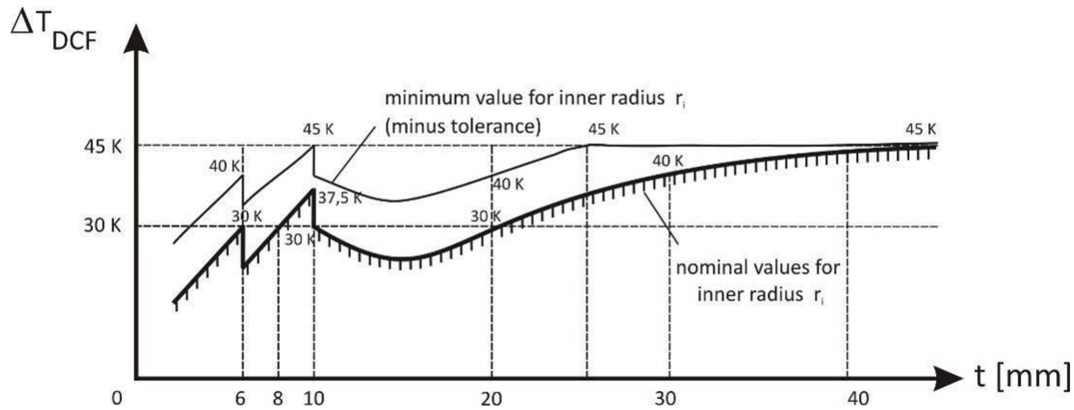


Figure 6-5: Dependency of ΔT_{DCF} on plate thickness t

(13) Figure 6-5 gives the temperature shifts ΔT_{DCF} to determine the reference temperature T^*_{Ed} for cold-formed rectangular hollow sections:

$$T^*_{Ed} = T_{Ed} - \Delta T_{DCF} \tag{6-3}$$

(14) Table 2-1 of EN 1993-1-10 is limited to +10 °C/-50 °C, the range has been extended to cover the temperature range (+10 °C/-120 °C), see Table 6-6.

(15) As indicated in Figure 6-5, for nominal values of r_i and t ≤ 16 mm the mean value ΔT_{DCF} would be about 30 K, for which the value ΔT_{DCF} = 35 K has been chosen to have a safe-sided value without considering thickness effects within the given limits.

A more conservative value ΔT_{DCF} for all thicknesses and also the minimum values r_i would be ΔT_{DCF} = 45 K.

(16) The evaluation according to approach no. 2 will clarify whether these values are acceptable.

6.2 Approach no. 2

(1) The procedure in section 6.1 gives a safe-sided estimate on the basis of properties of the base material according to EN 10025 for cold-formed hollow sections, that is used to compare with the more appropriate approach no. 2.

(2) The more appropriate approach would be to identify a specific value $\Delta\Delta T_R$ as the difference between the statistics of measured material properties in the fracture mechanics tests without cold-forming (ΔT_R = +38 °C) see Figure 1-3 and the nominal values in EN 10219 with cold-forming effect such, that from the differences between this $\Delta\Delta T_R$-value and the value $\Delta\Delta T_R$ = -45 K as used in EN 1993-1-10 an appropriate ΔT_{DCF}-value can be concluded.

(3) The problem is that the maximum cold-forming effects are in the corner region of the cross-section where no nominal values are indicated in the standards, nominal values in EN 10219 are related to the plane area, which contains also cold-forming effects from production.

(4) Another problem is that toughness values T_{27J} specified in EN 10219 are related to the standard CVN-test with strain-gradient, and that the EN 1993-1-10 requires a constant ε_{pl}-distribution over the critical cross-section of the CVN-test specimen for calculating cold-forming effects.

(5) These problems require a particular procedure that includes the following aspects:

1. Cold-forming effects can only be identified from the differences of toughness values measured at the corner region and the plane region.

   Due to the lack of knowledge on the properties of the feed-material without cold-forming the effect of cold-forming in the plane region cannot be determined from the measured data but need the use of the model for DCF in EN 1993-1-10.

2. Measured data including cold-forming effects need corrections to eliminate effects of strain gradient, position of specimen in the wall of the cross-section, and change of triaxiality of stress state, if the standard size of test specimen is not used.

(6) The thorough analysis of the data carried out in section 8 shows that the measured data are not sufficient to overrule the conclusions from approach no. 1, so that the effect of the application of approach no. 2 is mainly to confirm the results of approach no. 1 as relevant for determining ΔT_{DCF}.

Table 6-6: Choice of steel material to avoid brittle fracture (table 2.1 of EN 1993-1-10 extended, absolute values)

Steel grade	Sub-grade	Charpy energy CVN at T [°C]	J_{min}	Reference temperature T_{Ed} [°C]																																							
				σ_{Ed} = 0,75 fy(t)														σ_{Ed} = 0,50 fy(t)														σ_{Ed} = 0,25 fy(t)													
				10	0	-10	-20	-30	-40	-50	-60	-70	-80	-90	-100	-110	-120	10	0	-10	-20	-30	-40	-50	-60	-70	-80	-90	-100	-110	-120	10	0	-10	-20	-30	-40	-50	-60	-70	-80	-90	-100	-110	-120
S235	JR	+20	27	62	51	43	36	30	25	21	18	16	14	12	11	10	9	90	77	65	55	47	41	35	31	27	24	21	19	18	16	134	116	101	88	77	67	59	53	47	42	39	35	33	31
	J0	0	27	89	74	62	51	43	36	30	25	21	18	16	14	12	11	125	106	90	77	65	55	47	41	35	31	27	24	21	19	176	154	134	116	101	88	77	67	59	53	47	42	39	35
	J2	-20	27	126	106	89	74	62	51	43	36	30	25	21	18	16	14	169	146	125	106	90	77	65	55	47	41	35	31	27	24	199	199	176	154	134	116	101	88	77	67	59	53	47	42
S275	JR	+20	27	54	45	37	31	26	22	18	15	13	11	10	9	8	7	81	69	58	49	42	36	31	27	24	21	18	17	15	14	126	109	95	82	71	62	55	49	43	39	35	32	30	28
	J0	0	27	78	65	54	45	37	31	26	22	18	15	13	11	10	9	113	96	81	69	58	49	42	36	31	27	24	21	18	17	167	145	126	109	95	82	71	62	55	49	43	39	35	32
	J2	-20	27	112	94	78	65	54	45	37	31	26	22	18	15	13	11	156	133	113	96	81	69	58	49	42	36	31	27	24	21	199	191	167	145	126	109	95	82	71	62	55	49	43	39
	M, N	-20	40	132	111	93	77	64	53	44	37	31	25	21	18	15	13	179	154	132	112	95	81	68	58	49	42	36	31	27	23	199	199	189	165	144	125	108	94	81	71	62	55	48	43
	ML, NL	-50	27	185	158	134	112	94	78	65	54	45	37	31	26	22	18	199	199	181	156	133	113	96	81	69	58	49	42	36	31	229	202	199	199	191	167	145	126	109	95	82	71	62	55
S355	JR	+20	27	43	35	29	24	20	16	14	11	10	8	7	6	5	5	68	57	48	40	34	29	25	21	18	16	14	13	11	10	112	97	83	72	62	54	47	42	37	33	30	27	25	23
	J0	0	27	63	52	43	35	29	24	20	16	14	11	10	8	7	6	96	80	68	57	48	40	34	29	25	21	18	16	14	13	150	130	112	97	83	72	62	54	47	42	37	33	30	27
	J2	-20	27	92	76	63	52	43	35	29	24	20	16	14	11	10	8	133	113	96	80	68	57	48	40	34	29	25	21	18	16	198	173	150	130	112	97	83	72	62	54	47	42	37	33
	K2,M,N	-20	40	109	91	75	62	51	42	35	28	23	19	16	13	11	9	155	132	112	95	80	67	56	47	40	34	28	24	21	18	199	197	172	149	129	111	96	83	71	62	54	47	41	37
	ML, NL	-50	27	155	131	110	92	76	63	52	43	35	29	24	20	16	14	199	181	156	133	113	96	80	68	57	48	40	34	29	25	210	199	199	198	173	150	130	112	97	83	72	62	54	47
S420	M, N	-20	40	95	79	65	53	44	36	29	24	19	16	13	11	9	7	139	118	99	83	70	58	49	41	34	29	24	20	17	15	199	183	159	138	118	102	87	75	64	55	48	42	37	33
	ML, NL	-50	27	137	115	96	80	66	54	44	36	29	24	20	16	13	11	190	164	140	119	100	84	71	59	49	41	34	29	24	21	199	199	199	185	160	139	119	103	88	75	65	56	48	42
S460	Q	-20	30	77	63	52	42	34	28	23	18	15	12	10	8	7	6	116	98	82	68	57	47	39	33	27	23	19	16	14	12	183	159	137	118	101	86	74	63	54	47	41	36	31	28
	M, N	-20	40	88	73	60	49	40	32	26	21	17	14	12	9	8	6	130	110	93	78	65	54	45	37	31	26	22	18	16	14	199	176	152	131	113	96	82	71	61	52	45	39	34	30
	QL	-40	30	112	93	77	63	52	42	34	28	23	18	15	12	10	8	160	137	116	98	82	68	57	47	39	33	27	23	19	16	199	199	183	159	137	118	101	86	74	63	54	47	41	36
	ML, NL	-50	27	128	107	89	73	60	49	40	33	27	22	18	14	12	10	180	155	132	111	94	78	65	54	45	38	31	26	22	19	199	199	199	177	153	132	114	97	83	71	61	53	45	39
	QL1	-60	30	157	133	112	93	77	63	52	42	34	28	23	18	15	12	199	186	160	137	116	98	82	68	57	47	39	33	27	23	222	199	199	199	183	159	137	118	101	86	74	63	54	47
S690	Q	0	40	39	31	25	20	16	13	10	8	6	5	3	2	-	-	65	54	44	36	30	24	20	16	13	11	9	8	6	5	120	102	87	73	62	52	44	38	32	28	24	21	18	16
	Q	-20	30	52	42	34	27	21	17	13	11	8	7	5	4	2	1	84	69	57	47	38	31	26	21	17	14	12	10	8	7	147	126	107	91	77	65	55	46	39	34	29	25	22	19
	QL	-20	40	60	48	39	31	25	20	16	13	10	8	6	5	3	2	95	79	65	54	44	36	30	24	20	16	13	11	9	8	164	141	120	102	87	73	62	52	44	38	32	28	24	21
	QL	-40	30	78	64	52	42	34	27	21	17	13	11	8	7	5	4	120	100	84	69	57	47	38	31	26	21	17	14	12	10	197	171	147	126	107	91	77	65	55	46	39	34	29	25
	QL1	-40	40	89	73	60	48	39	31	25	20	16	13	10	8	6	5	135	114	95	79	65	54	44	36	30	24	20	16	13	11	199	189	164	141	120	102	87	73	62	52	44	38	32	28
	QL1	-60	30	113	94	78	64	52	42	34	27	21	17	13	11	8	7	166	142	120	100	84	69	57	47	38	31	26	21	17	14	199	199	197	171	147	126	107	91	77	65	55	46	39	34

Note: *The values in this table are for some parameters slightly different to those given in Table 2.1 of EN 1993-1-10. In a future revision of Table 2.1 of EN 1993-1-10 the values of Table 6-6 could be adopted.*

7 Approach to determine admissible plate thicknesses for cold-formed sections from measured product properties according to EN 10219 (Approach no. 2)

7.1 General

(1) In this section the procedures for the analysis of data from CNV-tests collected in annex A are given to obtain the relevant data for the evaluation.

(2) To this end the treatment of measured data to obtain T_{27J}-values and the correction of these T_{27J}-values to comply with the conditions of EN 1993-1-10 is explained.

(3) The further processing of the T_{27J}-data is in section 8.

7.2 Reference situation for the interpretation of Charpy-V-tests

(1) The standard case of the KV-T relationship considered in EN 1993-1-10 is given by a curve with upper-shelf-toughness properties, lower shelf properties and a transition behaviour, see Figure 7-1.

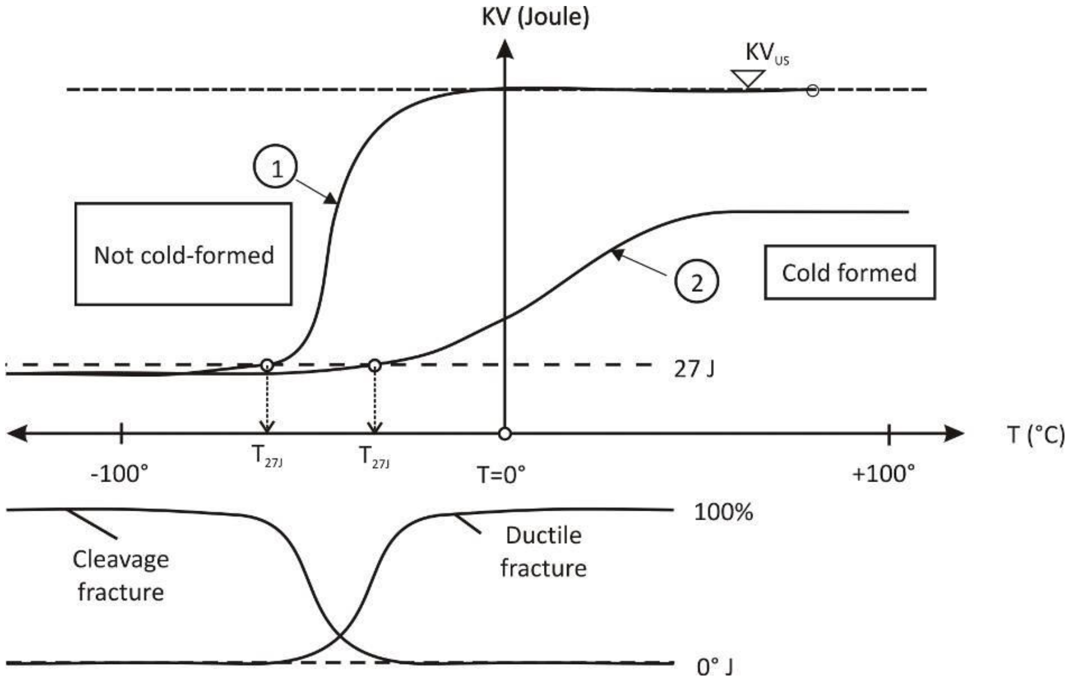


Figure 7-1: Reference curve for the KV-T-relationship

(2) The fracture type in the upper-shelf range is ductile, whereas in the lower shelf range cleavage fracture prevails.

(3) The value T_{27J} characterizes the behaviour in the transition part of the KV-T curve and constitutes the reference value for the Master Curve Concept to fracture mechanics that allows to perform a quantitative safety assessment to avoid brittle fracture.

(4) The weak link of the assessment procedure is the scatter of the Charpy test results at a certain temperature especially in the transition range and the problem of determining T_{27J} values from data T_{KV} and KV.

(5) The procedure in EN 1993-1-10 covers the model uncertainty produced by the scatter of the various parameters and correlations applied and the scatter of measured values of KV by calibration of the method to test results with large scale tests using an appropriate test evaluation according to EN 1990. The result of the procedure is Table 2.1 of EN 1993-1-10.

7.3 Particular methods for the evaluation of test results KV, T_{KV} for cold-formed hollow sections to obtain T_{27J}-values

7.3.1 Determination of T_{27J}-values from curve fitting

(1) In general the Charpy-V-impact tests to identify temperature effects yield data that can be plotted in a KV-T-diagram, see Figure 7-2.

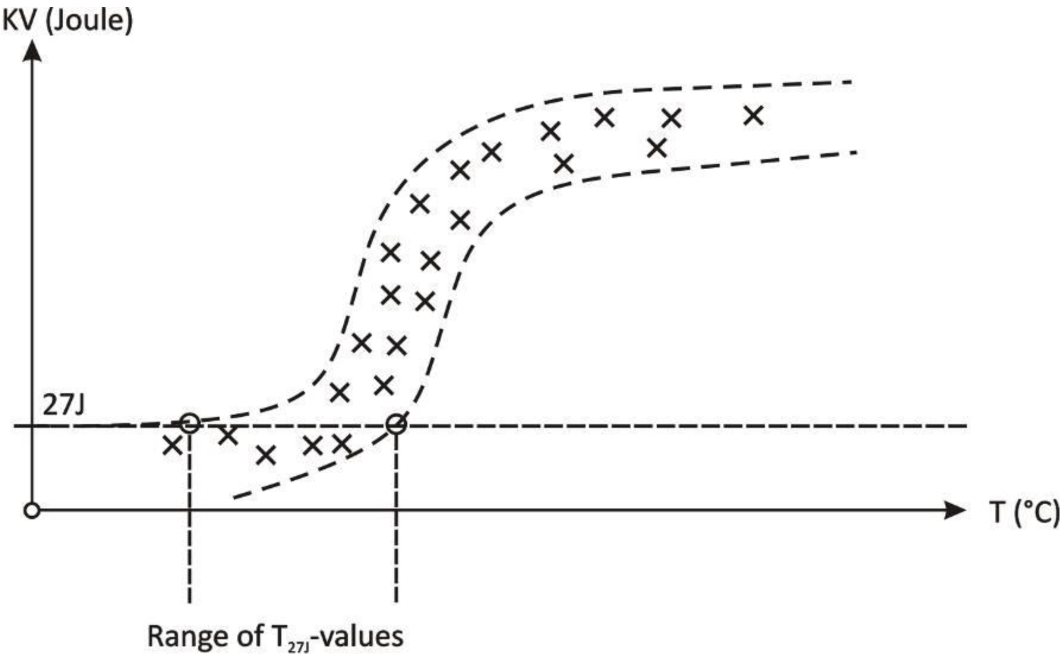


Figure 7-2: Range of T_{27J}-values

(2) If the measured data are uniformly distributed along the temperature-axis the evaluation of data may be performed by using a mathematical function as an approximation of the data. This mathematical function represents the mean of the data in the upper-shelf region, the lower shelf region and the transition area:

$$KV = A\left[1+\tanh\frac{T-B}{C}\right] \quad \textbf{(7-1)}$$

with A, B, C = fitting coefficients.

Fitting is performed by eye or by a minimum square fit to obtain the mean value curve.

From this mean value curve, the T_{27J}-value is determined.

(3) In case sufficient test results KV are available in the range

$$16J \leq KV \leq 67J \quad \textbf{(7-2)}$$

see Figure 7-3, the test values may be used [2] to determine the approximation associated with each pair KV, T_{KV}:

$$T_{27J} = T_{KV} + 41{,}33 - 8{,}16\sqrt{KV - 1{,}373} \quad \textbf{(7-3)}$$

From various such approximations the mean value T_{27J} may be used.

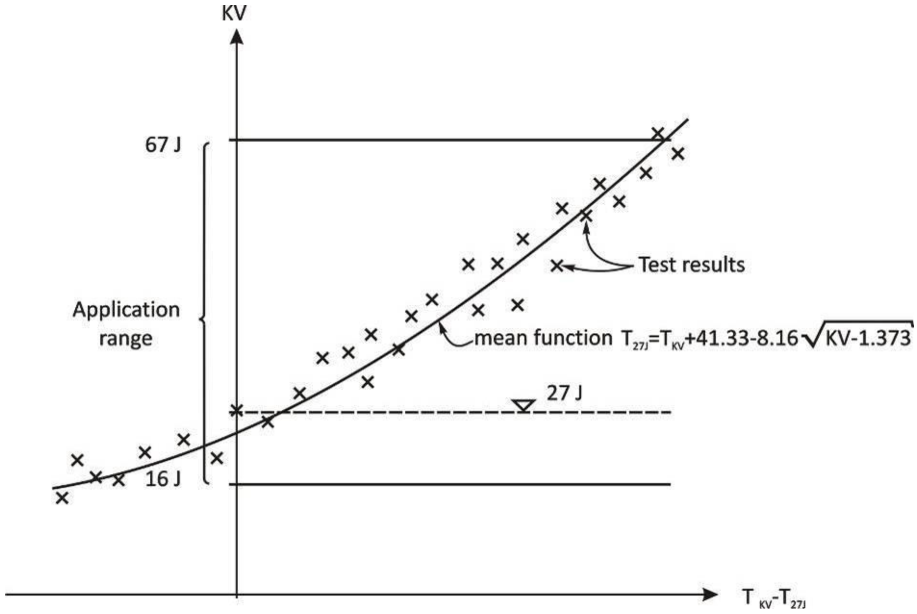


Figure 7-3: Determination of T_{27J} from temperatures T_{KV} for notch impact energies KV in the range of 16J to 67 J

7.3.2 Determination of T_{27J}-values from standardised transition curves

(1) In assuming an idealised transition curve as given in Figure 7-4,

where

- KV_{US} is the Charpy-V-energy in the upper-shelf,
- T_{US} is the lowest temperature for the upper-shelf behaviour,

a mathematical transformation of the ordinate can be performed to obtain two asymptotic lines.

$$\overline{KV} = \frac{KV}{KV_{US}} \cdot \frac{1}{1 - \dfrac{KV}{KV_{US}}} = \frac{KV}{KV_{US} - KV}$$

$$\overline{KV}_{27J} = \frac{27\text{J}}{KV_{US}} \cdot \frac{1}{1 - \dfrac{27\text{J}}{KV_{US}}} = \frac{27\text{J}}{KV_{US} - 27\text{J}} \qquad \textbf{(7-4)}$$

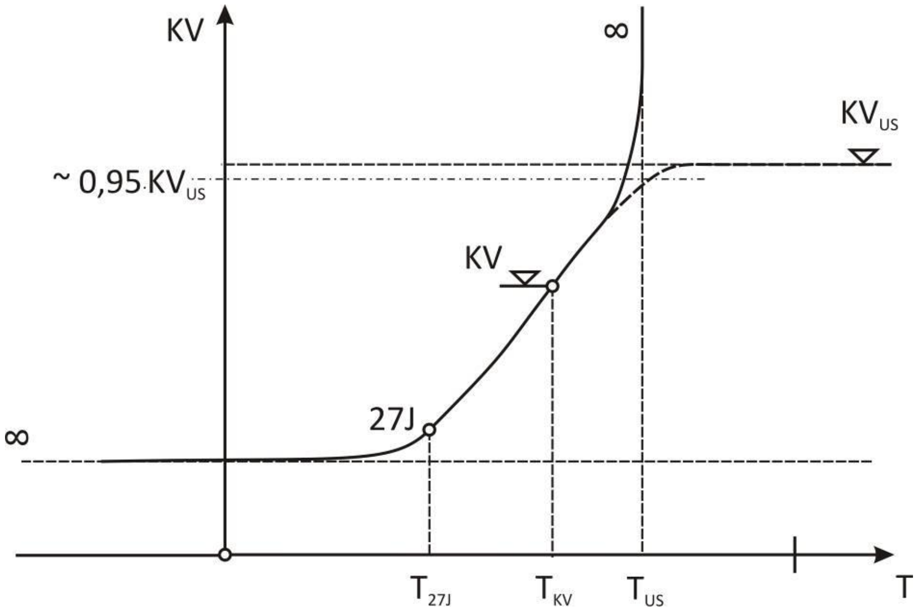


Figure 7-4: Idealised temperature-toughness transition curve

(2) By expressing the transition curve in the semi-logarithmic scale, it is represented by a straight line, see Figure 7-5 with the slope C*.

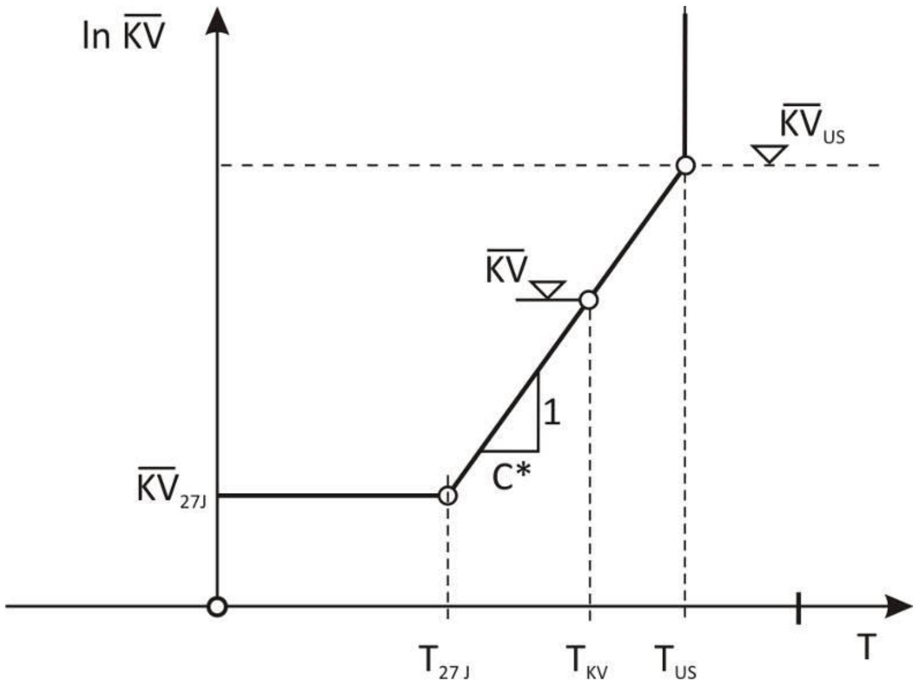


Figure 7-5: Idealised transition curve in semi-logarithmic scale

(3) From Figure 7-5 follows

$$T_{KV} - T_{27J} = C^* \cdot \left[\ln\left(\overline{KV}\right) - \ln\left(\overline{KV}_{27J}\right)\right] \quad \textbf{(7-5)}$$

$$= C^* \cdot \ln\left[\frac{KV}{KV_{US} - KV} \cdot \frac{KV_{US} - 27\text{J}}{27\text{J}}\right]$$

$$= C^* \cdot \ln\left[\frac{KV}{27\text{J}} \cdot \frac{KV_{US} - 27\text{J}}{\text{KV}_{\text{US}} - \text{KV}}\right]$$

(4) This gives the formula in [19][20][21]

$$T_{27J} = T_{KV} - C^* \cdot \ln\left[\frac{KV}{27\text{J}} \cdot \frac{\left(KV_{US} - 27\text{J}\right)}{\left(KV_{US} - KV\right)}\right] \quad \textbf{(7-6)}$$

where

C^* is the slope of the KV-T transition curve in [°C], conservatively determined by

$$C^* \approx \frac{1}{4}\left\{34°C + \frac{f_y}{35{,}1} - \frac{KV_{US}}{14{,}3}\right\} \quad \textbf{(7-7)}$$

(5) For the case that no KV-values in the transition range are available, the value T_{27J} can be estimated with the KV_{US}-value at the minimum upper-shelf test temperature T_{US} by assuming a 95 %-value as an approximation to the asymptotic line KV_{US}, see Figure 7-4:

$$KV = 0{,}95 \cdot KV_{US} = \frac{19}{20} \cdot KV_{US}$$

which gives from equation

$$T_{27J} = T_{us} - C^* \ln\left[\frac{19\left(KV_{us} - 27J\right)}{27J}\right] \quad \textbf{(7-8)}$$

Note: In these formulas the values KV_{US} and T_{US} are not defined by testing standards. Therefore in this evaluation KV_{US} is taken as the mean value of the KV-data in the upper shelf area and T_{US} is estimated visually as the temperature at the beginning of the temperature transition area (~ $0{,}95 \cdot KV_{US}$), see Figure 7-4.

7.3.3 Irregularities

(1) The evaluation methods given in section 7.3.1 and 7.3.2 are also used where no data in the transition area of notch energy-temperature diagram are available.

(2) Then the steels exhibit a “bi-modal behaviour” as given in Figure 7-6, that has been observed in particular from steels produced with thermo-mechanical rolling.

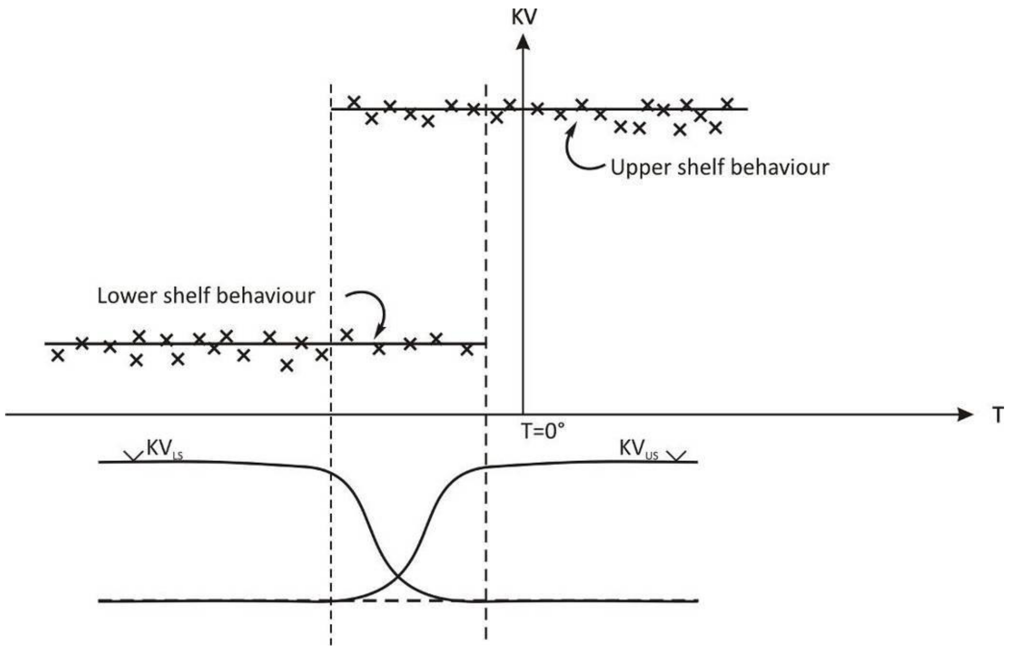


Figure 7-6: Typical bi-modal distribution of impact energy

(3) The test results for such “bi-modal behaviour” in the upper-shelf and lower shelf may be overlapping so that the evaluation of the test results is performed in the following way:

- The approximation in formula (7-1) is used as an interpolation function to determine T_{27J} as a value with a low probability of attaining upper-shelf behaviour.
- The minimum temperature T_{US} for the upper-shelf energy KV_{US} is used as a conservative substitute of T_{27J}.

(4) Cold-forming may in this case only have an effect on the KV-value in the upper-shelf without consequences for the T_{27J}-values.

(5) It has also been observed that due to thermo-mechanical rolling the dislocation density of steels may have reached such a state, that with respect to Figure 2-2 the limit of the linear relationship between cold-forming DCF and T_{DCF} (DCF ~ 15 %) is already met. In consequence cold-forming does not influence the toughness-behaviour any more.

(6) These irregularities have however so far not yet been investigated such, that systematic conclusions can be drawn, where they occur and to what extent.

(7) Therefore they are not specifically treated in this report.

7.4 Corrections of measured data

7.4.1 General

(1) Measured data as documented from Charpy-V-tests from cold-formed sections are only comparable with measured data that have been used for

developing the assessment procedure in EN 1993-1-10 if the conditions for measurements comply.

(2) To achieve compliance the following corrections of measured data are introduced:

1. Corrections for undersized test specimen. These corrections are applicable for test specimen with the width w < 10 mm.
2. Corrections due to a position of test specimen that does not include the maximum strain ε_{pl} as assumed in averaging the strain distribution for the test-specimen.
3. Corrections of measured values of T_{27J} in the flat part of cold-formed sections to link to the material properties of feed-material for cold-forming.

7.4.2 Effects of undersized test specimen

(1) In case of undersized samples with w < 10 mm, which are applied for plate-thickness t < 11 mm (w = t – 2 x 0,5 mm for machining) the impact energies are given in terms of [Joule/cm^2] and with a correlation factor to cope with the effects of triaxiality of the stress-state, that depends on the magnitudes of w (the smaller w the more the equal strain distribution develops to the equal stress state), see Figure 7-7.

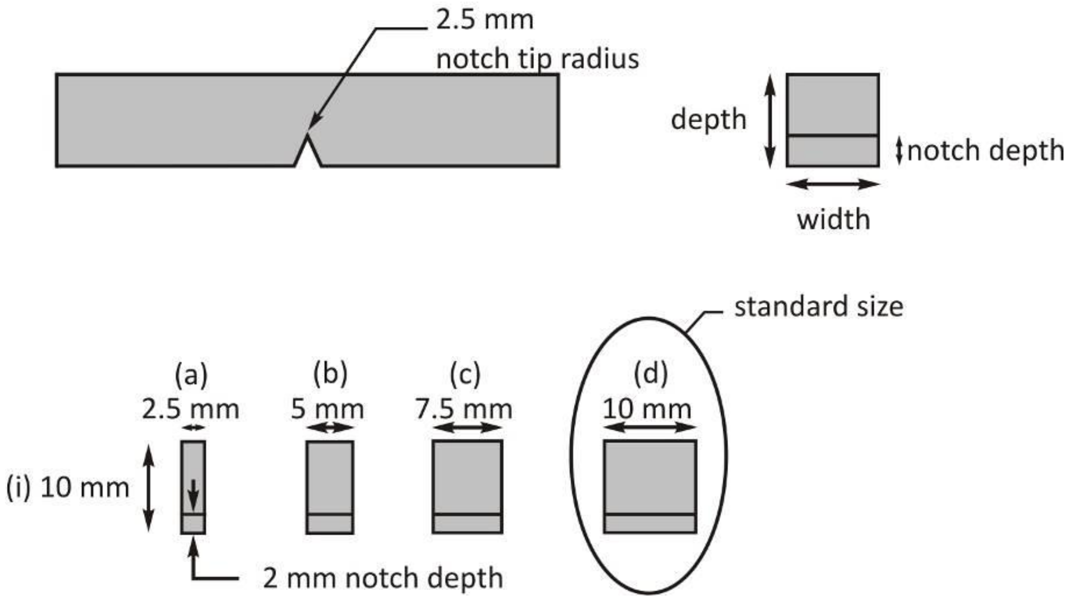


Figure 7-7: Charpy "Subsize" impact test specimens acc. to ASTM E23 [15]

(2) This correlation factor takes into account, that temperatures T_{KV} as measured are the more favourable, the smaller the effects of triaxiality of stress state in the test specimen are.

(3) The temperature shift due to the modification of the triaxiality of the stress state may be estimated according to [20][21] with

$$\Delta T_{ss} = -51{,}4 \; x \ln\left(2\left(\frac{w}{10}\right)^{0{,}25} - 1\right) \qquad \textbf{(7-9)}$$

An upper-shelf estimate can be conservatively taken as

$$KV_{US}(\text{Charpyspecimen}) \geq KV_{US}(w)\frac{10\,mm}{w} \qquad \textbf{(7-10)}$$

where

$KV_{us}(w)$ is the upper-shelf energy for the specimen of thickness w.

The formulae should not be used below 5 mm thickness. Figure 7-8 gives the values ΔT_{ss} versus the thickness w.

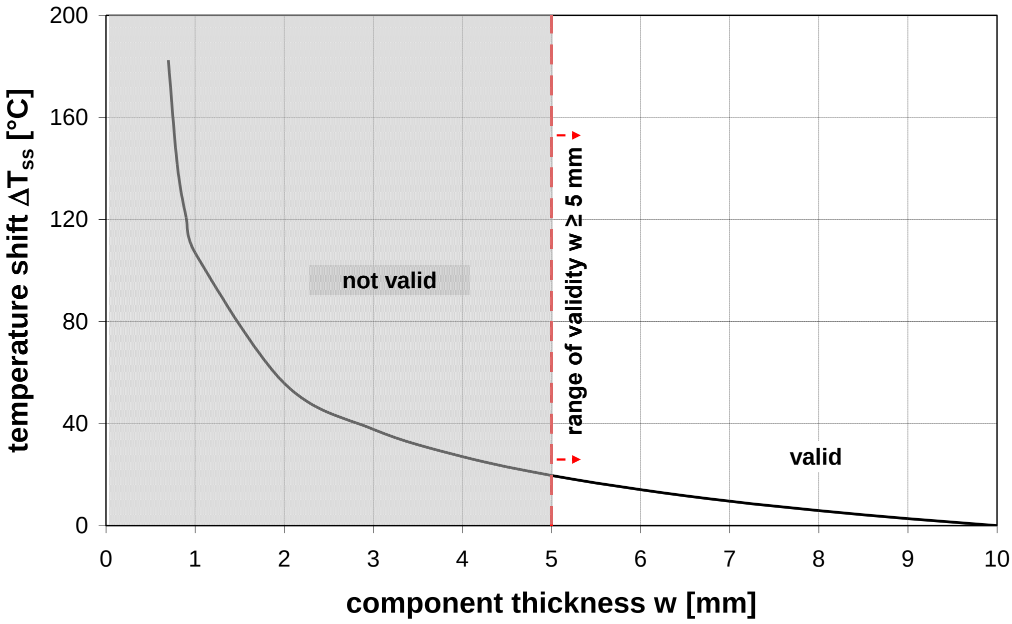


Figure 7-8: Temperature shift ΔT_{ss} due to sub-sized Charpy-V-test-specimens

(4) Another method may be drawn from Table 1 in ASTM A673/A637M that gives shifts of KV-values determined from Charpy-V-tests to $\overline{\overline{KV}}$ -values reduced by undersized test specimens.

By using the relationship in formula (7-3) the temperature shift ΔT_{ss} may be determined from:

$$\Delta T_{ss} = -8{,}16 \cdot \left(\sqrt{KV - 1{,}373} - \sqrt{\overline{\overline{KV}} - 1{,}373}\right) \qquad \textbf{(7-11)}$$

in the range of 16 J ≤ KV ≤ 67 J.

(5) Figure 7-9 gives a comparison of the temperature shifts according to formula (7-9) and (7-11).

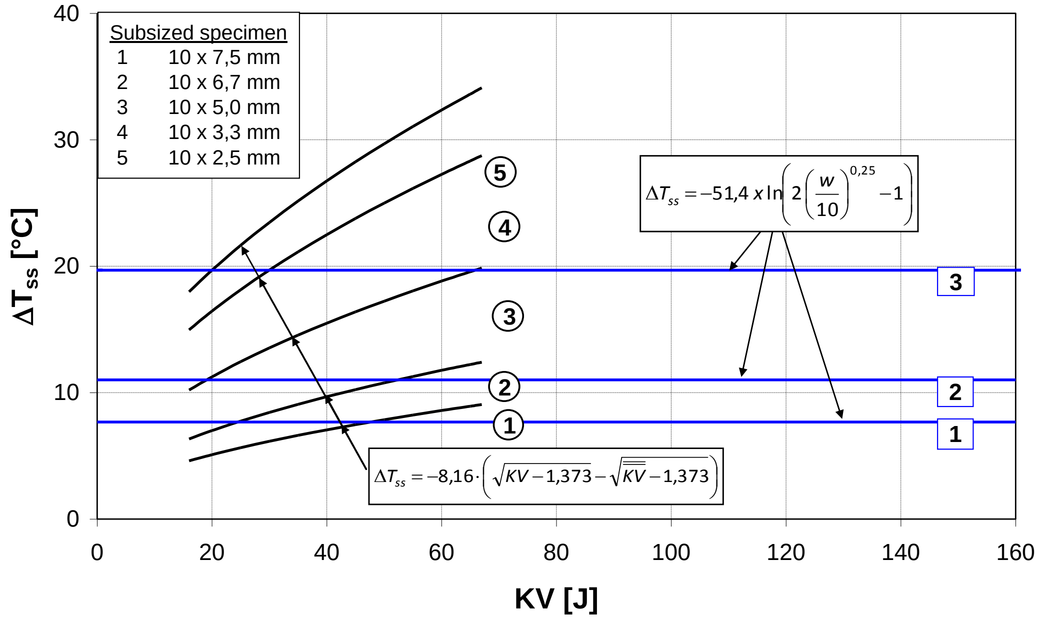


Figure 7-9: Comparison of temperature shifts from formula (7-9) and formula (7-11)

(6) For a value KV = 27 J the values ΔT_{ss} according to formula (7-9) and (7-11) are indicated in Table 7-1.

Table 7-1: Temperature shift due to undersized specimens

plate thickness t [mm]	Charpy width w [mm]	formula (7-9) ΔT_{ss} [K]	formula (7-11) ΔT_{ss} [K]
6	5	19,69	12,89
7	6	14,09	9,89
8	7	9,62	7,15
9	8	5,90	4,61
10	9	2,74	2,24

(7) The relevant range is 8 mm < t < 11 mm. As formula (7-9) gives conservative values, this formula is used for the correction of measured data.

7.4.3 Effects of position of sample and gradient of strain

(1) Cold-formed areas in cold-formed hollow-sections do not exhibit a field of uniform strain but a strain field with a strain gradient.

(2) It is assumed that the mean-value of strain in the critical cross section of the Charpy-V-specimen is the effective strain equivalent to a uniformly distributed strain as supposed in the formula for ΔT_{DCF}.

(3) Hence two position of the test specimen are distinguished for samples taken at the outside of the radius:

1. position close to the surface with a maximum strain value ε_{pl} and a notch perpendicular to the surface, see Figure 7-10a,
2. position close to the surface with the notch parallel to the surface, see Figure 7-10b.

The same applies to the position of the sample at the inner radius

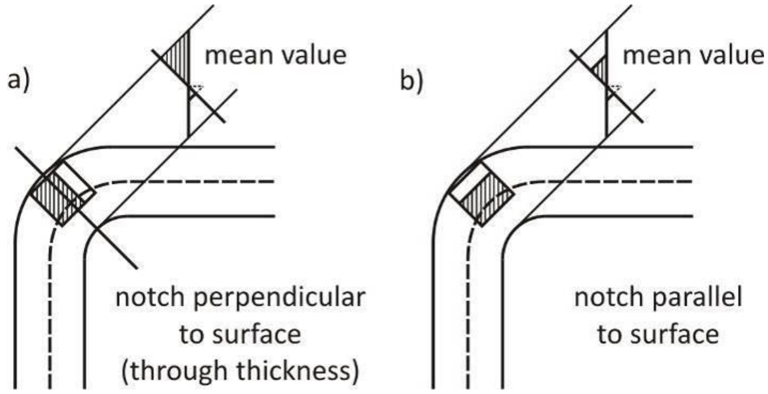


Figure 7-10: Sampling positions of CVN-specimens

(4) The test evaluation therefore contains a correction from the location of the test-specimen, by a temperature shift ΔT_{pos} to transform the results to the case in Figure 6-3 with a notch transverse to the surface and close to the surface, see Figure 7-10a and Figure 7-10b. The position in Figure 7-10a and Figure 7-10b is marked by the distance z_e of the net-section of the CNV-test specimen to the surface of the wall.

(5) The correction is performed conservatively with ΔT_{DCF} = 3 x DCF, where DCF is defined as $\Delta\varepsilon$ according to Figure 7-11a and Figure 7-11b.

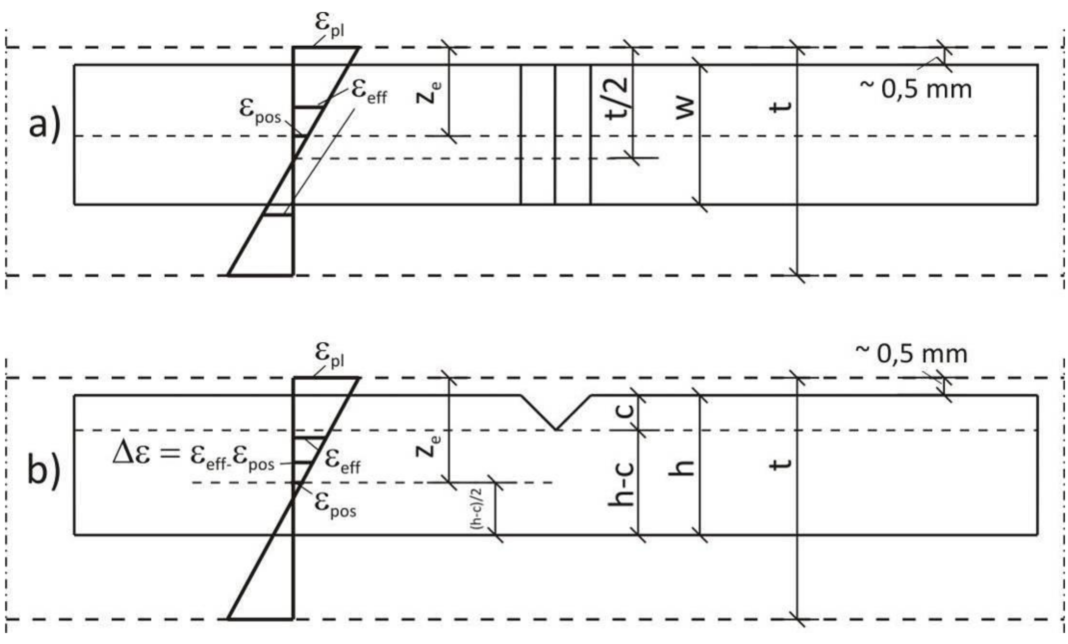


Figure 7-11: Definition of $\Delta\varepsilon$

(6) Furthermore, ε_{pos} can be determined by using eq. (7-12)

$$\varepsilon_{pos} = \frac{\varepsilon_{pl}}{t/2} \cdot \left| \frac{t}{2} - z_e \right| \tag{7-12}$$

where z_e reads:

$z_e = \sim 0{,}5 + \frac{w}{2}$	for perpendicular notch orientation acc. to Figure 7-11a
$z_e = \sim 0{,}5 + c + \frac{h-c}{2}$	for parallel notch orientation acc. to Figure 7-11b

7.4.4 Correction of measured values T_{27} in the flat parts to link to the feed-material properties

(1) It is assumed that all cold-formed sections for which measured data exist have been produced according to the "universal forming" process so that the flat parts have undergone an effective straining that can be considered by ΔT_{DCF} according to Table 6-1 using r_i/t-values from equation (6-1).

7.4.5 Conclusions

(1) The temperature shifts ΔT_{pos} due to the favourable position of the test specimen and ΔT_{ss} due to favourable triaxiability of the test specimens, all related to the test conditions in Figure 7-10, that are the basis for calculation ΔT_{DCF} in Figure 6-5, are given in Table 7-2.

(2) The temperature shifts ΔT_{DCF} for the flat parts of cross section to consider the local cold-forming effects from the "universal forming" process in this part are given in Table 7-3.

(3) Table 7-2 and Table 7-3 are used for the further test evaluation.

Table 7-2: Temperature shift due to favourable location and favourable triaxiality of test specimens

	test no.	profile	profile dimensions corner area				CVN thick ness	CVN width	notch depth	geom. quantiys ee Figure 7-11	effects of favour. triax.	Calculated values profile corner area		effects of favourable position of specimen		ε_{eff}-ε_{pos}		total ΔT_{ss}+ΔT_{pos}	
			r_a	r_i	t	r_i/t	h	w	c	z_e	ΔT_{ss}	ε_{pl}	ε_{eff}	ε_{pos}		$\Delta\varepsilon$	ΔT_{pos}	ΔT_{total}	
			[mm]	[mm]	[mm]	[-]	[mm]	[mm]	[mm]	[mm]	[K]	[-]	[-]		[-]	[-]	[K]	[K]	
CIDECT 1A	B0121	150x150x8	20,9	12,0	8	1,50	8	10	1,6	5,80	-	0,25	0,10	ε_{pl}/2,2	0,11	0,01	3,75	3,75	**1**
	A22	100x100x8	21,9	12,6	8	1,58	8	10	1,6	5,80	-	0,25	0,10	ε_{pl}/2,2	0,11	0,01	3,75	3,75	**2**
	A32	100x100x10	32,5	23,0	10	2,30	8	10	1,6	6,30	-	0,25	0,13	ε_{pl}/3,8	0,07	0,06	18,00	18,00	**3**
	B32	100x100x10	24,6	12,0	10	1,20	8	10	1,6	6,30	-	0,25	0,13	ε_{pl}/3,8	0,07	0,06	18,00	18,00	**4**
	A0221	150x150x8	21,0	13,4	8	1,67	8	10	1,6	5,80	-	0,25	0,10	ε_{pl}/2,2	0,11	0,01	3,75	3,75	**5**
	B0261	150x150x10	25,5	14,9	10	1,49	8	10	1,6	6,30	-	0,25	0,13	ε_{pl}/3,8	0,07	0,06	18,00	18,00	**6**
	B23	100x100x8	18,0	12,0	8	1,50	8	10	1,6	5,80	-	0,25	0,10	ε_{pl}/2,2	0,11	0,01	3,75	3,75	**7**
	B0321	150x150x8	19,8	12,6	8	1,58	8	10	1,6	5,80	-	0,25	0,10	ε_{pl}/52,2	0,11	0,01	3,75	3,75	**8**
CIDECT 1B	1B-1	254x254x15,9	31,8	15,9	15,9	1,00	10	10	2	6,50	-	0,20	0,08	ε_{pl}/5,5	0,04	0,05	14,49	14,49	**9**
	1B-2	102x102x12,7	25,4	12,7	12,7	1,00	10	10	2	6,50	-	0,20	0,08	ε_{pl}/42,3	0,00	0,08	23,93	23,93	**10**
	1B-3	250x250x12,5	37,5	25,0	12,5	2,00	10	10	2	6,50	-	0,20	0,09	ε_{pl}/25,0	0,01	0,08	23,10	23,10	**11**
	1B-4	255x255x8,4	16,0	7,9	8,4	0,95	5	10	1	6,00	-	0,25	0,11	ε_{pl}/2,3	0,11	0,00	0,64	0,64	**12**
Dagg	Dagg-1	203x203x9,5	19,1	9,5	9,5	1,00	10	5	1	3,00	19,7	0,25	0,12	ε_{pl}/2,7	0,09	0,03	7,99	27,68	**13**
	Dagg-2	76x76x6,3	12,7	6,4	6,3	1,01	10	5	1	3,00	19,7	0,25	0,08	ε_{pl}/21	0,01	0,07	20,05	39,74	**14**
Ruukki		220x220x9,5	25,0	12,5	12,5	1,00	10	10	2	6,50	-	0,20	0,09	ε_{pl}/25	0,01	0,08	23,10	23,10	
	Ruukki-1	150x150x12,5	37,5	25,0	12,5	2,00	10	10	2	6,50	-	0,20	0,09	ε_{pl}/25	0,01	0,08	23,10	23,10	
		250x250x10	30,0	20,0	10	2,00	10	7,5	2	5,25	7,7	0,25	0,13	ε_{pl}/20	0,01	0,11	33,75	41,43	**19**
	Ruukki-2	300x100x8	20,0	12,0	8	1,50	10 1) 7 2)	8,0 1) 10 2)	2 1) 1,4 2)	5,50 1) 6,20 2)	5,9 1) - 2)	0,25 1) 0,25 2)	0,10 1) 0,10 2)	ε_{pl}/2,7 1) ε_{pl}/1,8 2)	0,09 1) 0,14 2)	0,01 1) 0,04 2)	1,88 1) 11,25 2)	7,78 1) 11,25 2)	**20**
	Ruukki-3	250x250x12,5	37,5	25,0	12,5	2,00	10	10	2	6,50	-	0,20	0,09	ε_{pl}/25	0,01	0,08	23,10	23,10	**21**
	Ruukki-4	200x200x12,5	37,5	25,0	12,5	2,00	10	10	2	6,50	-	0,20	0,09	ε_{pl}/25	0,01	0,08	23,10	23,10	**22**
Soininen	Soininen-1	100x100x10	30,0	20,0	10	2,00	10	10	2	5,50	-	0,25	0,13	ε_{pl}/10	0,03	0,10	30,00	30,00	**23**
	Soininen-2	150x150x8	20,0	12,0	8	1,50	10	8	2	4,50	5,9	0,25	0,10	ε_{pl}/8	0,03	0,07	20,63	26,53	**24**
	Soininen-3	200x200x12,4	37,5	25,0	12,5	2,00	10	10	2	5,50	-	0,20	0,09	ε_{pl}/8,3	0,02	0,06	18,30	18,30	**25**

(shaded) *Results of evaluation not considered in conclusions, see Annex A*

1) *flat face*
2) *corner region*

Table 7-3: Temperature shift due to cold-forming in flat parts of rectangular cross sections produced by "universal forming" process

	Test no.	profile	profile dimensions corner area				profile dimensions flat area				max value	effective value	ΔT_{DCF} (=2x3xε_{eff})
			r_a [mm]	r_i [mm]	t [mm]	r_i/t [-]	b [mm]	t [mm]	b/t [-]	r_i/t [-]	ε_{pl} [%]	ε_{eff} [%]	[K]
CIDECT 1A	B0121	150x150x8	20,9	12,5	8	1,50	150	8	18,75	11,40	4,20	1,68	10
	A22	100x100x8	21,9	12,6	8	1,58	100	8	12,50	7,46	6,28	2,51	15
	A32	100x100x10	32,5	23,0	10	2,30	100	10	10,00	5,87	7,85	3,92	24
	B32	100x100x10	24,6	12,0	10	1,20	100	10	10,00	5,87	7,85	3,92	24
	A0221	150x150x8	21,0	13,4	8	1,67	150	8	18,75	11,44	4,19	1,68	10
	B0261	150x150x10	25,5	14,9	10	1,49	150	10	15,00	9,05	5,24	2,62	16
	B23	100x100x8	18,0	12,8	8	1,50	100	8	12,50	7,46	6,28	2,51	15
	B0321	150x150x8	19,8	12,6	8	1,58	150	8	18,75	11,44	4,19	1,68	10
CIDECT 1B	1B-1	254x254x15,9	31,8	15,9	15,9	1,00	254	15,9	15,97	9,67	4,92	2,08	13
	1B-2	102x102x12,7	25,4	12,7	12,7	1,00	102	12,7	8,03	4,61	9,78	4,13	25
	1B-3	250x250x12,5	37,5	25,0	12,5	2,00	250	12,5	20,00	12,23	3,93	1,67	10
	1B-4	225x225x8,4	16,0	7,9	8,4	0,95	255	8,4	30,36	18,83	2,59	1,09	7
Dagg	Dagg-1	203x203x9,5	19,1	9,5	9,5	1,00	203	9,5	21,37	13,10	3,68	1,75	10
	Dagg-2	76x76x6,3	12,7	6,4	6,3	1,01	79	6,3	12,54	7,18	6,57	2,05	12
Ruukki		220x220x9,5	25,0	12,5	12,5	1,00	220	12,5	23,16	14,24	4,42	1,88	10
	Ruukki-1	150x150x12,5	37,5	25,0	12,5	2,00	150	12,5	12,00	7,14	6,54	2,78	17
		250x250x10	30,0	20,0	10	2,00	250	10	25,00	15,42	3,14	1,57	9
	Ruukki-2	300x100x8	20,0	12,0	8	1,50	200	8	25,00	15,42	3,14	1,26	8
	Ruukki-3	250x250x12,5	37,5	25,0	12,5	2,00	250	12,5	20,00	12,23	3,93	1,67	10
	Ruukki-4	200x200x12,5	37,5	25,0	12,5	2,00	200	12,5	16,00	9,69	4,91	2,09	13
Soininen	Soininen-1	100x100x10	30,0	20,0	10	2,00	100	10	10,00	5,87	7,85	3,92	24
	Soininen-2	150x150x8	20,0	12,0	8	1,50	150	8	18,75	11,44	4,19	1,68	10
	Soininen-3	200x200x12,4	37,5	25,0	12,5	2,00	200	12,5	16,13	9,77	4,91	2,09	12

Results of evaluation not considered in conclusions, see Annex A

8 Evaluation of test data for rectangular cold-formed hollow sections

8.1 Procedure

(1) The test data plotted in Annex A.1, Annex A.2, Annex A.3 and Annex A.4 have been evaluated with curve fitting according to 7.3.1(2) and (3).

(2) In the following the evaluation of the Charpy-V-tests considers the experimental results from the longitudinal oriented Charpy-V-specimen.

(3) The results for the upper-shelf characteristics KV_{US} and T_{US} and for the T_{27J}-values as evaluated from the measured values are given in Table 8-1.

(4) In the following the data in Table 8-1 are analysed to answer the following questions:

1. Is the quality of the steels of the test specimen homogeneous?
2. What are the effects of the larger degree of cold-forming in the corner area in relation to the plane area?
3. What are the magnitudes of T_{27J}-values in the feed material and the cold-formed areas of hollow sections and do they comply with the rules determined for the temperature shift ΔT_{cf} in Figure 2-2?
4. What are the effects of quality-differentiation?

(5) As the tests have been carried out mainly with hollow sections made of S355J2H-material the conclusions refer to this material.

8.2 Upper-shelf toughness properties and T_{27J}-values

(1) Figure 8-1 gives the pairs of values (KV_{US}, T_{US}) for the upper-shelf region covered by the tests available for the plane area of cross section. This figure shows that the majority of the cold-formed hollow sections included in this study are based on high quality steels, that, even after cold-forming in the plane area, exceed the toughness requirements T_{27J} for any steel grade in EN 10219 by far. These toughness requirements are indicated in Figure 8-1 as functions KV-T_{KV} starting at the specified T_{27J}-values for J2-steels, K-, M-, N-steels and ML- and NL-steels by using formula (7-8).

Table 8-1: Values of upper-shelf characteristics and of T_{27J} as evaluated from measurements (without corrections)

No. of eval.	test series	steel grade	prod. method	test no.	location and treatment								
					plane			bent			bent & aged		
					KV_{us} [J]	T_{us} [°C]	T_{27J} [°C]	KV_{us} [J]	T_{us} [°C]	T_{27J} [°C]	KV_{us} [J]	T_{us} [°C]	T_{27J} [°C]
1	CIDECT 1A	S275J2H	OS	B0121	225	-10	-39	200	-20	-37	200	-20	-37
2	CIDECT 1A	S355J2H	TM-FG	A22	240	-60	-81	240	-70	-89	200	-70	-86
3	CIDECT 1A	S355J2H	TM-FG	A32	190	-30	-45	210	-40	-56	180	-40	-69
4	CIDECT 1A	S355J2H	FG	B32	180	-10	-47	170	-20	-37	215	-70	-71
5	CIDECT 1A	S355J2H	TM-FG	A0221	285	-70	-88	235	-70	-85	250	-60	-102
6	CIDECT 1A	S355J2H	FG	B0261	200	0	-32	185	-10	-40	190	+20	-32
7	CIDECT 1A	S460MLH	TM	B23	205	-20	-37	160	-30	-39	200	-70	-90
8	CIDECT 1A	S460MLH	TM	B0321	260	-20	-68	250	-50	-59	250	-50	-67
9	CIDECT 1B	A500C	OS	1B-1	205	0	-31	200[1)] 185[2)]	+20[1)] +20[2)]	-3[1)] -21[2)]			
10	CIDECT 1B	A500C	OS	1B-2	170	+20	+3	150[2)] 165[2)]	+20[2)] +10[2)]	+4[2)] -13[2)]			
11	CIDECT 1B	S355J2H	TM-FG	1B-3	340	-50	-89	235[1)] 300[2)]	-30[1)] -20[2)]	-71[1)] -74[2)]			
12		A53B		1B-4	55	-40	-74	55[1)] 55[2)]	-50[1)] -50[2)]	-54[1)] -59[2)]			
13	DAGG			Dagg-1	50	-30	-39	65	-30	-40			
14	DAGG			Dagg-2	60	-30	-53	65	-30	-57			
15	Ruukki	S355J2H		R-1				220	-40	-60			
16	Ruukki	S355J2H		R-1				175	-50	-66			
17	Ruukki	S355J2H		R-1				135	-60	-76			
18	Ruukki	S355J2H		R-1				160	-50	-96			
19	Ruukki	S355J2H		R-1				240	-40	-72			
20	Ruukki	S355J2H	TM-FG	R-2	165	-80	-104	105[1)] 100[2)]	-70[1)] -50[2)]	-96[1)] -90[2)]			
21	Ruukki	S355J2H	TM-FG	R-3	230	-50	-97	230[1)] 270[2)]	-70[1)] -50[2)]	-95[1)] -98[2)]			
22	Ruukki	S355J2H	TM-FG	R-4	255	-60	-86	295[1)] 305[2)]	-80[1)] -60[2)]	-100[1)] -99[2)]			

Table 8-1: **continued**

No. of eval.	test series	steel grade	prod. method	test no.	location and treatment								
					plane			bent			bent & aged		
					KV_{us} [J]	T_{us} [°C]	T_{27J} [°C]	KV_{us} [J]	T_{us} [°C]	T_{27J} [°C]	KV_{us} [J]	T_{us} [°C]	T_{27J} [°C]
23	SOININEN	S355J2H	OS	S-1	180	0	-20	200	+10	-38	175	+10	-20
24		S355J2H	OS	S-2	120	-10	-68	130	+10	-63	110	-30	-55
25		S355J2H	OS	S-3	180	-10	-27	170	0	-22	180	+10	-18

Note 1: *OS* *ordinary steel*
TM-FG *thermo-mechanically rolled micro-alloyed fine grain steel*
FG *micro-alloyed fine grain steel*

Note 2: ▢ *Results of evaluation not considered in conclusions, see Annex A.*

Index: *1)* *Inner notch*
2) *Outer notch*

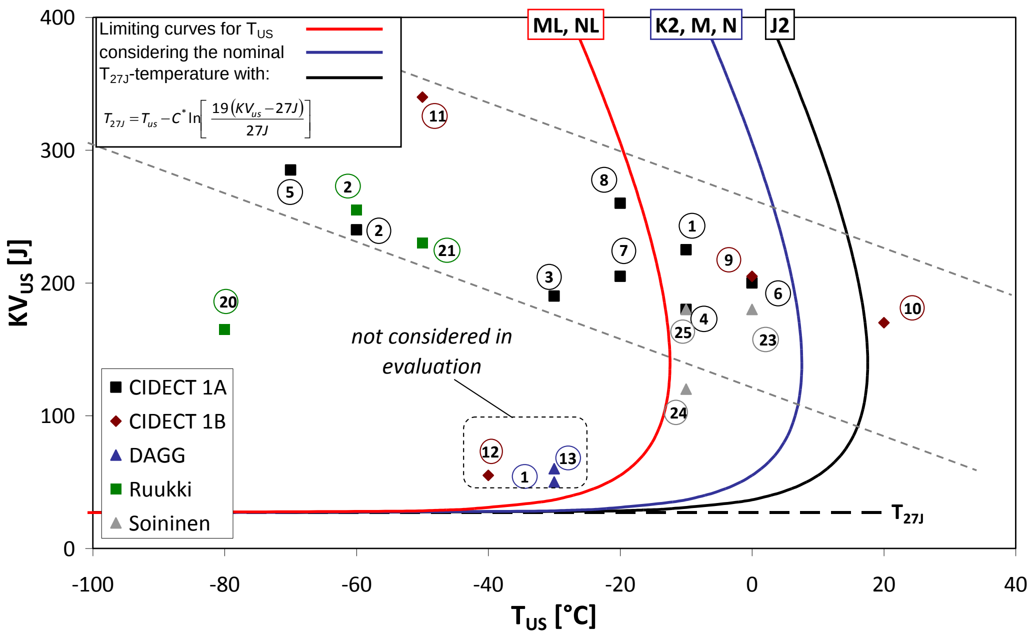


Figure 8-1: **Upper-shelf characteristics of steels KV_{US} and T_{US} in cold-formed rectangular hollow sections (data from plane areas)**

(2) Figure 8-2 gives a comparison of the upper-shelf characteristics KV_{US} and T_{US} for the plane area and the corner area. Some of the lines (○ flat → □ bent) reflect the tendency, that by the larger degree of cold-forming in the corner area the KV_{US}–values in this area are somewhat lower and the T_{US}-values are shifted to the right. Some of the results appear to contradict this tendency and are illogical. This may be caused by the large scatter of the CVN-test

results and also by small differences between the flat face and the bent area due to the averaging out of cold-forming effects by the strain gradient and the position of the test specimens in the strain-field.

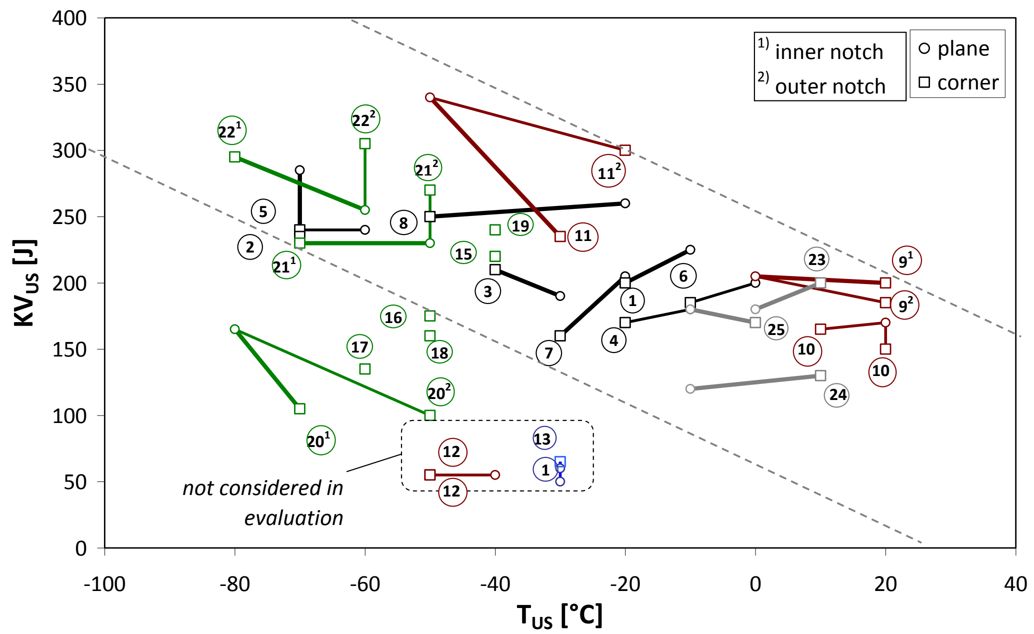


Figure 8-2: Comparison of KV_{US}-values and T_{US}-values in the plane area (○) and corner area (□) of cold-formed rectangular hollow sections

(3) Mean values from all results in Figure 8-2 are

- for the plane area KV_{US} = 190 J
  T_{US} = -28°C
- for the bent area KV_{US} = 184 J
  T_{US} = -38 °C

(4) Figure 8-3 and Figure 8-4 give for the plane and the bent area the tendency for the relation between T_{US} and T_{27J} as measured. Apparently there is in the mean a linearity between T_{US} and T_{27} that can be expressed as follows:

- for the plane area: $T_{27J} = T_{US} - 29°C$
- for the bent area: $T_{27J} = T_{US} - 32°C$ **(8-1)**
- in average: $T_{27J} = T_{US} - 31°C$

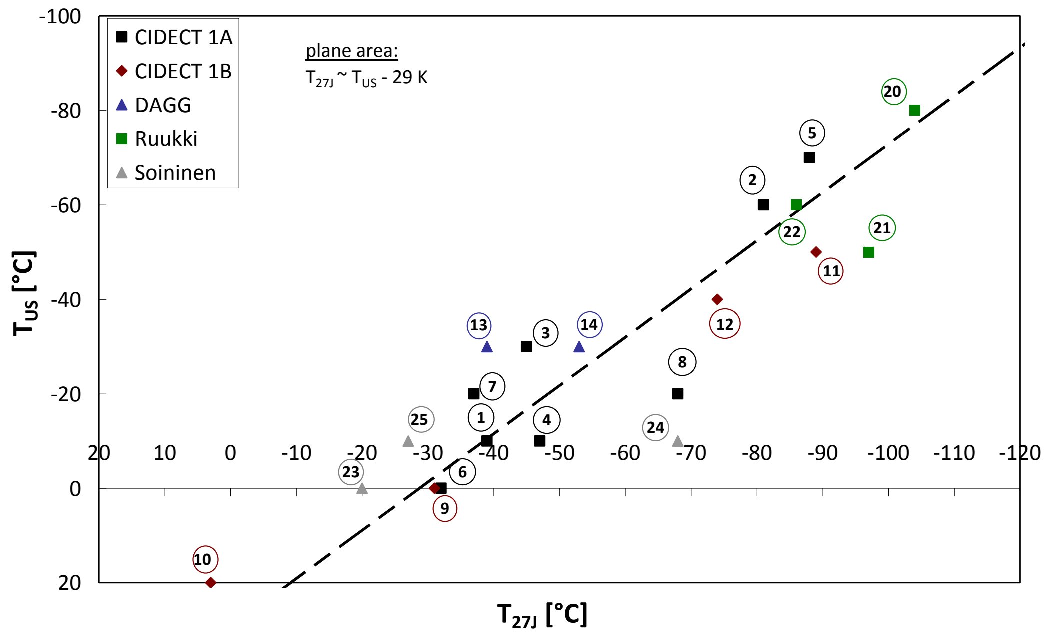


Figure 8-3: **Relationship between T_{US} and T_{27J} of cold-formed rectangular hollow sections as measured in the plane area**

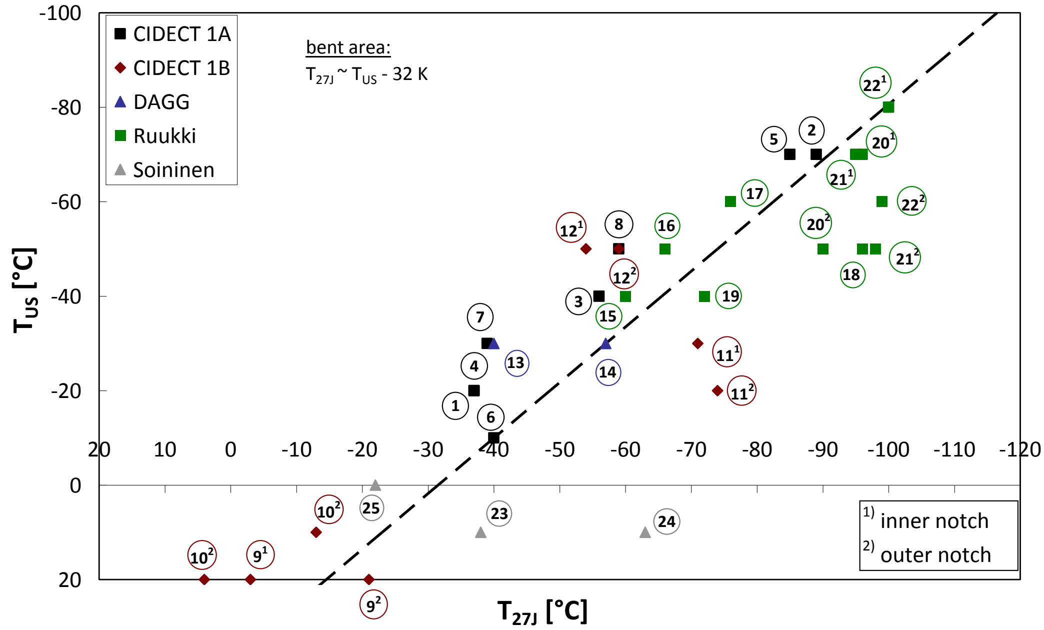


Figure 8-4: **Relationship between T_{US} and T_{27J} of cold-formed rectangular hollow sections as measured in the bent area**

(5) This linear relationship between T_{US} and T_{27J} explains why the band in Figure 8-1 with KV_{US} and T_{US} is shifted by ~ 29 K to the left for giving the band KV_{US} and T_{27J}, see Figure 8-5. The KV_{US}-values are the larger, the lower the temperature T_{27J} is.

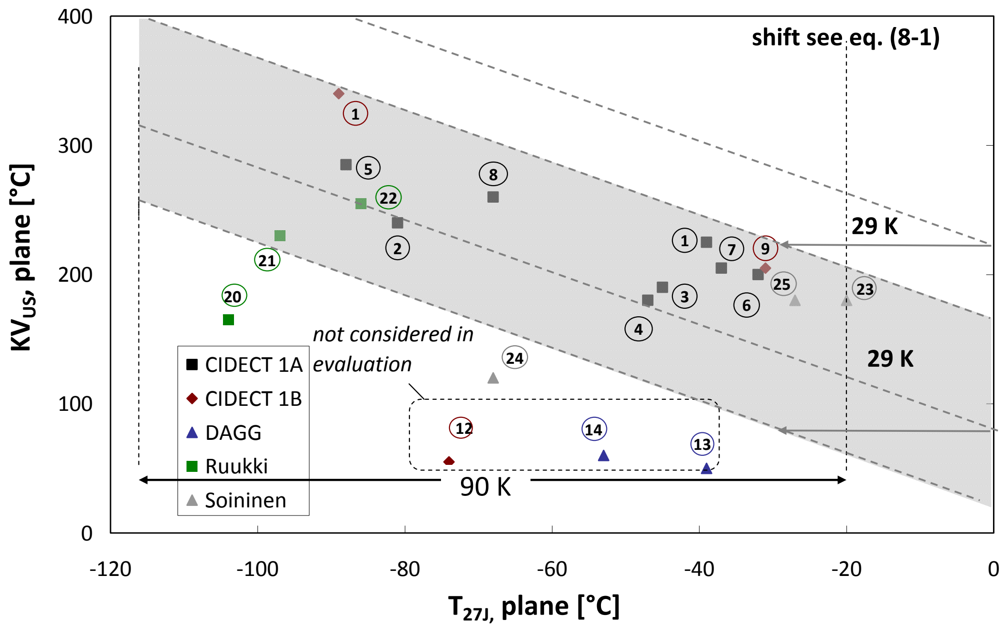


Figure 8-5: Relationship between KV_{US} and T_{27J} of cold-formed rectangular hollow sections in the plane area

(6) Figure 8-6 finally gives the ratios between the value $KV_{US,plane}$ and $KV_{US,bent}$, and Figure 8-7 illustrates the ratios between $T_{27J,plane}$ and $T_{27,bent}$. Both pairs of values give good correlations.

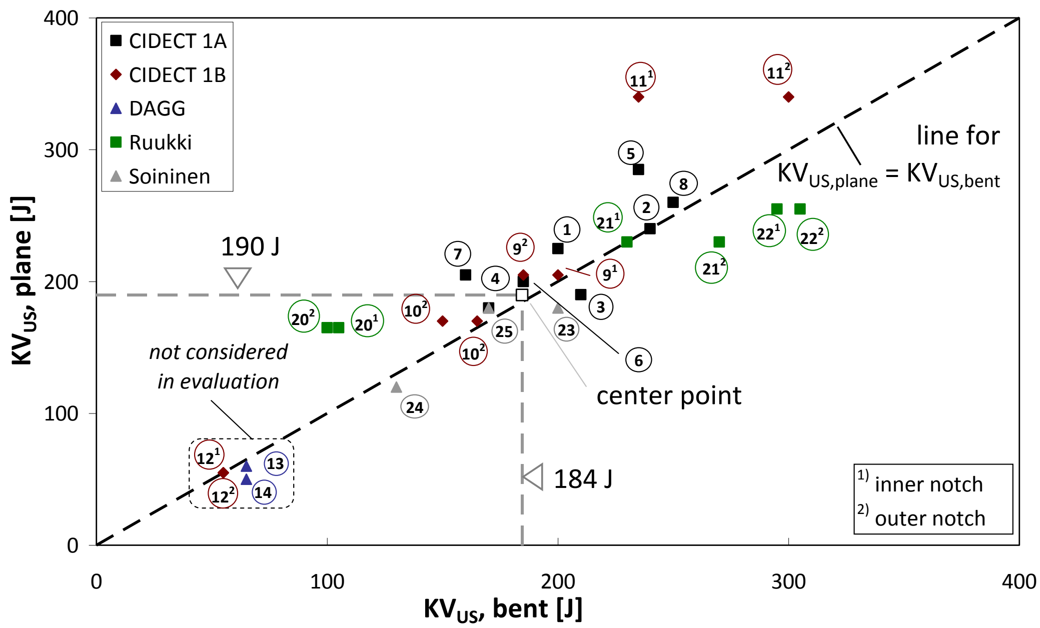


Figure 8-6: Ratios between $KV_{US,plane}$ and $KV_{US,bent}$ of cold-formed rectangular hollow sections

(7) As indicated in Figure 8-7 the mean values of $T_{27J,plane}$ and $T_{27J,bent}$ as measured are very closely together:

- for ordinary steels (No. 1, 9, 10, 23, 24, 25) there is a small difference

  mean $T_{27J,plane}$ = -30 °C

  mean $T_{27J,bent}$ = -26 °C

- for micro-alloyed fine grain steels and thermo-mechanically rolled steels (No. 2, 3, 5, 7, 8, 11, 20, 21, 22) the difference is negligible

  mean $T_{27J,plane}$ = -77 °C

  mean $T_{27J,bent}$ = -81 °C

- for all steels

  mean $T_{27J,plane}$ = -56 °C

  mean $T_{27J,bent}$ = -59 °C

(8) The values $T_{27J,plane}$ and $T_{27J,bent}$ as measured cannot be used directly to determine the temperature shift ΔT_{DCF} for EN 1993-1-10. They need corrections to obtain T_{27J}-values for the feed-material for cold-forming and T_{27J}-values representing the effects of effective strain from cold-forming on the other side, see 8.3.

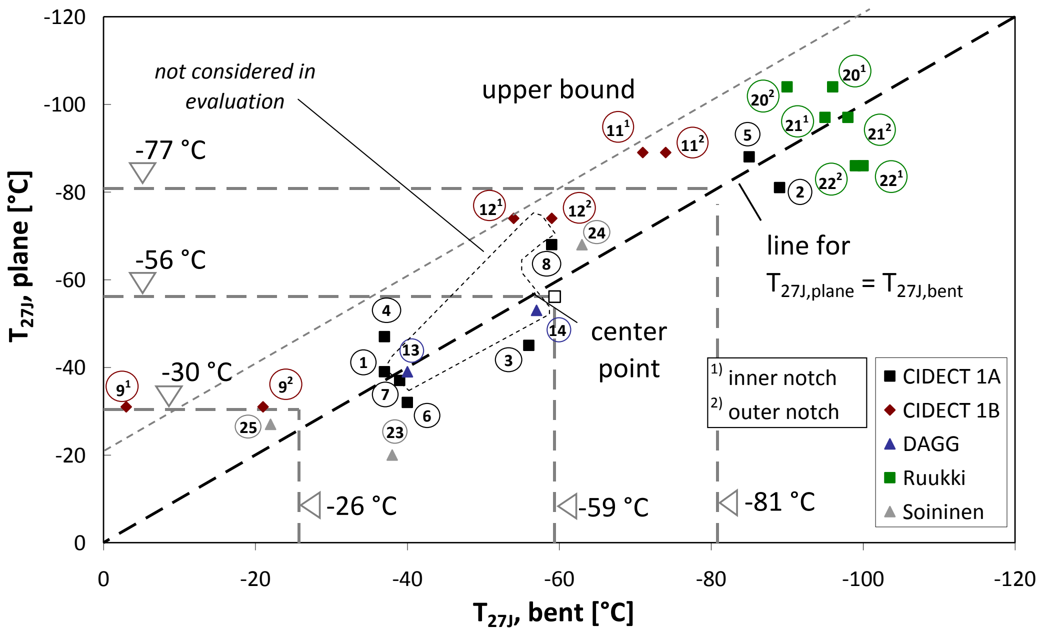


Figure 8-7: Ratios between $T_{27J,plane}$ and $T_{27J,bent}$ of cold-formed rectangular hollow sections

(9) In view of the small differences between the measured values $T_{27J,plane}$ and $T_{27J,bent}$, see Figure 8-8, the temperature shifts ΔT to obtain corrected values $T_{27J,plane,corrected}$ and $T_{27J,bent,corrected}$, that are in line with the assumptions in EN 1993-1-10, will give the main differences that are used to determine ΔT_{DCF}

from cold-forming, see 8.3 (10) and Figure 8-10. The results for ΔT_{DCF} can be expected as very similar to the values given in Figure 6-5.

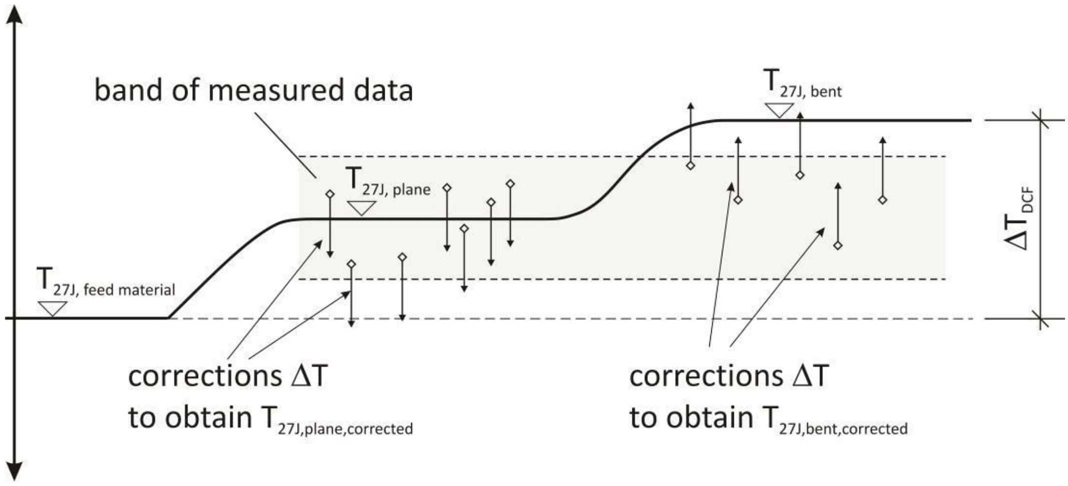


Figure 8-8: Band of measured data and effects of corrections ΔT and ΔT_{DCF}

8.3 Establishment of a link to EN 1993-1-10

(1) The rules in EN 1993-1-10 were developed for plates without significant cold-forming effects using correlations to Charpy-V-impact energy-tests with full size test specimens, see Figure 6-3 and a uniform plastic strain distribution ε_{pl} across the critical cross section of the test specimen.

(2) The test results given in Table 8-1 for the plane area contain already cold-forming effects from the production and may also be influenced by subsized test specimens, so that they do not reflect the situation that applies to the feed material for the production of cold-formed hollow sections, that is referenced according to EN 1993-1-10.

(3) The test results in Table 8-1 for the corner area contain a large value of plastic strain from cold-forming but these values may be influenced by a favourable position of the test specimen in the corner area and also by subsized test specimens, so that they do not give the full effect of cold-forming as assumed in EN 1993-1-10.

(4) Therefore, the test results given in Table 8-1 need corrections with temperature shifts as specified in section 7 to be compatible with the material input values used in EN 1993-1-10.

(5) Table 8-2 gives the T_{27J}-values as derived from the measurements and the corrected T_{27J}-values.

(6) The corrections are made in the following way:

1. For the bent corner region the measured T_{27J}-values are shifted to the right side of the temperature diagram, where the position of the sample (ΔT_{pos}) in the radiused area and the triaxiality of the subsized specimen (ΔT_{ss}) gave too favourable values. Hence

$$T_{27J,bent,corrected} = \underbrace{T_{27J,bent}}_{Table 8.2} + \underbrace{\Delta T_{pos} + \Delta T_{ss}}_{Table 7.2} \quad \textbf{(8-2)}$$

e.g. for No.1

$$T_{27J,bent,corrected} = -37 + 3{,}75 = -33{,}25°C$$

2. For the plane region the measured values may contain cold-forming effects from the production ΔT_{DCF}, so that they should be shifted to the left side of the temperature diagram. Where the triaxiality of the subsized test specimen gave too favourable results, a further shift to the right is necessary. It is assumed that the test specimens are taken closely from the surface, so that no ΔT_{pos} is taken into account. Hence

$$T_{27J,plane,corrected} = \underbrace{T_{27J,plane}}_{Table 8.2} - \underbrace{\Delta T_{DCF}}_{Table 7.3} + \underbrace{\Delta T_{ss}}_{Table 7.2} \quad \textbf{(8-3)}$$

e.g. for No.1

$$T_{27J,plane,corrected} = -39 - 10 + 0{,}0 = -49{,}0°C$$

(7) The ratios between the corrected values $T_{27J,plane}$ and $T_{27J,bent}$ are given in Figure 8-9.

(8) In Figure 8-9 the values $T_{27J,plane,corrected}$ may be considered as estimates of the T_{27J}-values for the feed-material for cold-forming and the $T_{27J,bent,corrected}$ may be used as estimates of the T_{27J}-values in the corner area of the cold-formed sections in compliance with EN 1993-1-10.

(9) From Figure 8-9 the following conclusions may be drawn:

1. The scatter of all T_{27J}-values for the feed material ($T_{27J,plane,corrected}$) is about 90 K. This corresponds to the situation in Figure 1-3 (see 1(11)) with $\Delta\Delta T_R$ = -45 K, where the scatter band width is also 90 K.
2. The mean value of $T_{27J,bent,corrected}$ in the corner region of the cold-formed section is in the mean about 30 K higher than the T_{27J}-value for the feed material ($T_{27J,plane,\ corrected}$). This would result in ΔT_{DCF} = 30 K. In order to be safe-sided the choice ΔT_{DCF} = 35 K was made.

Table 8-2: T_{27J}-values and corrected T_{27J}-values from tests [°C]

No. of evaluation	test series	test no.	steel grade	location of sample						$T_{27J,plane,corr} - T_{27J,bent,corr}$
				plane		bent		bent & aged		
				T_{27J}	$T_{27J,corr}$	T_{27J}	$T_{27J,corr}$	T_{27J}	$T_{27J,corr}$	b_i
1	CIDECT 1A	B0121	S275J2H	-39	-49	-37	-33	-37	-33	-16
2		A22	S355J2H	-81	-96	-89	-85	-86	-82	-11
3		A32	S355J2H	-45	-69	-56	-38	-69	-51	-31
4		B32	S355J2H	-47	-71	-37	-19	-71	-53	-52
5		A0221	S355J2H	-88	-98	-85	-81	-102	-98	-17
6		B0261	S355J2H	-32	-48	-40	-22	-32	-14	-26
7		B23	S460MLH	-37	-52	-39	-35	-90	-86	-17
8		B0321	S460MLH	-68	-78	-59	-55	-67	-63	-23
9	CIDECT 1B	1B-1	A500C	-31	-44	-3[1)] -21[2)]	11[1)] -7[2)]			-55[1)] -37[2)]
10		1B-2	A500C	+3	-22	+4[2)] -13[2)]	28[2)] 11[2)]			-50[2)] -33[2)]
11		1B-3	S355J2H	-89	-99	-71[1)] -74[2)]	-48[1)] -51[2)]			-51[1)] -48[2)]
12		1B-4	A53B	-74	-81	-54[1)] -59[2)]	-53[1)] -58[2)]			-27[1)] -22[2)]
13	DAGG	Dagg-1	DAGG-1	-39	-30	-40	-12			-17
14		Dagg-2	DAGG-2	-53	-45	-57	-17			-28
15	Ruukki	R-1	S355J2H			-60	-37			
16		R-1	S355J2H			-66	-43			
17		R-1	S355J2H			-76	-35			
18		R-1	S355J2H			-96	-55			
19		R-1	S355J2H			-72	-49			
20		R-2	S355J2H	-104	-106	-96[1)] -90[2)]	-85[1)] -79[2)]			-21[1)] -27[2)]
21		R-3	S355J2H	-97	-107	-95[1)] -98[2)]	-72[1)] -75[2)]			-35[1)] -32[2)]
22		R-4	S355J2H	-86	-99	-100[1)] -99[2)]	-77[1)] -76[2)]			-22[1)] -23[2)]

Table 8-2: continued

No. of evaluation	test series	test no.	steel grade	location of sample: plane T_{27J}	plane $T_{27J,corr}$	bent T_{27J}	bent $T_{27J,corr}$	bent & aged T_{27J}	bent & aged $T_{27J,corr}$	$T_{27J,plane,corr}$ – $T_{27J,bent,corr}$ b_i
23	SOININEN	S-1	S355J2H	-20	-44	-38	-8	-20	10	-36
24		S-2	S355J2H	-68	-72	-63	-36	-55	-28	-36
25		S-3	S355J2H	-27	-39	-22	-4	-18	0	-36

Note: ▢ *Results of evaluation not considered in conclusions, see Annex A.*

Index: *1) Inner notch*
2) Outer notch

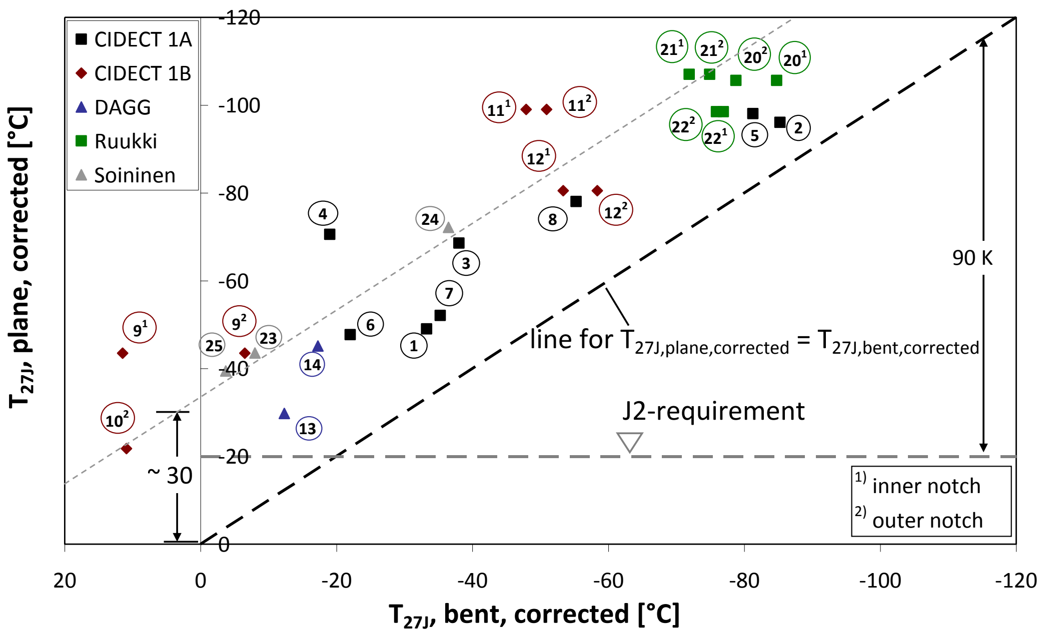


Figure 8-9: $T_{27J,plane,\ corrected}$ **versus** $T_{27J,bent,corrected}$

(10) Figure 8-10 demonstrates the values

$$b_i = T_{27J,bent,corr} - T_{27J,plane,corr} \tag{8-4}$$

versus the T_{27J}-values as measured in the plane area, without correction, i.e. the T_{27J}-values comparable with the T_{27J}specification in EN 10219.

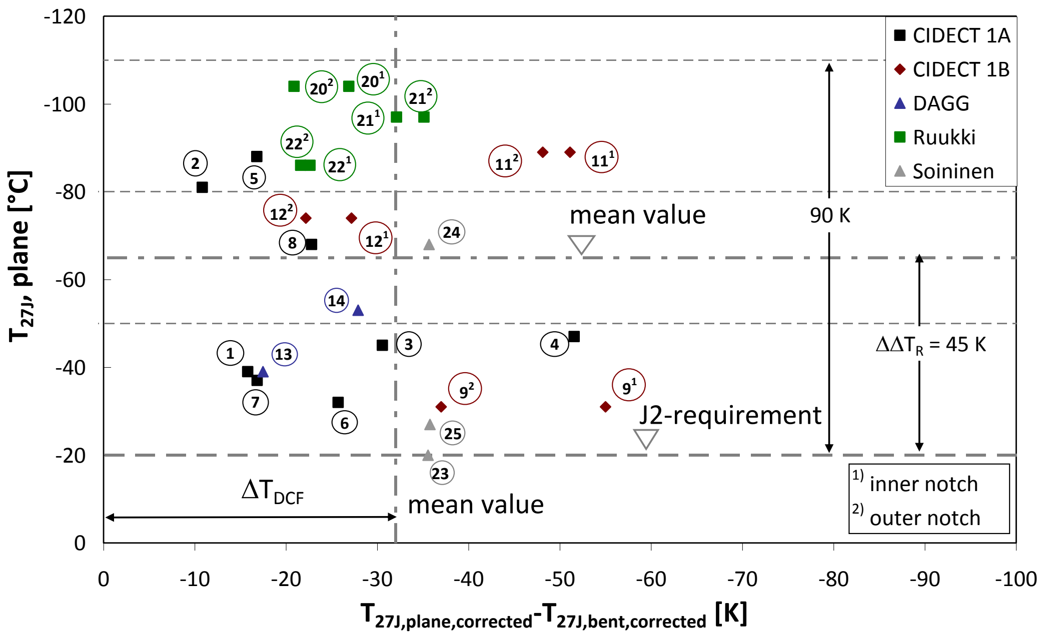


Figure 8-10: Values $b_i = T_{27J,plane,corr} - T_{27J,bent,corr}$ versus $T_{27J,plane}$, measured according to the EN 10219-specification

(11) Figure 8-10 demonstrates in a different way to Figure 8-9 the plausibility of the values $\Delta\Delta T_R$ = - 45 K (necessary to give an analogous situation as that in Figure 1-3) and ΔT_{DCF} = 30 K applicable to the cross section and steels tested, see Figure 8-9 and 6.1(15), for which the choice ΔT_{DCF} = 35 K was made.

(12) Hence the conclusion in 6.1(15) is confirmed and ΔT_{DCF} = 35 K can be used to apply EN 1993-1-10 for the choice of material for cold-formed sections for t ≤ 16 mm, whereas for larger thicknesses ΔT_{DCF} = 45 K should be used.

(13) This conclusion applies as long as the actual T_{27J}-values measured in the plane zone of the cold-formed sections exhibit values which fill the complete range of T_{27J} = -20 °C to T_{27J} = -110 °C uniformly, so that $\Delta\Delta T_R$ = 45 K can be maintained, see Figure 8-10.

(14) Figure 8-10 also opens the door for introducing subclasses of toughness properties in addition to the minimum requirement for J2-steels in EN 10219 as illustrated in Figure 8-11:

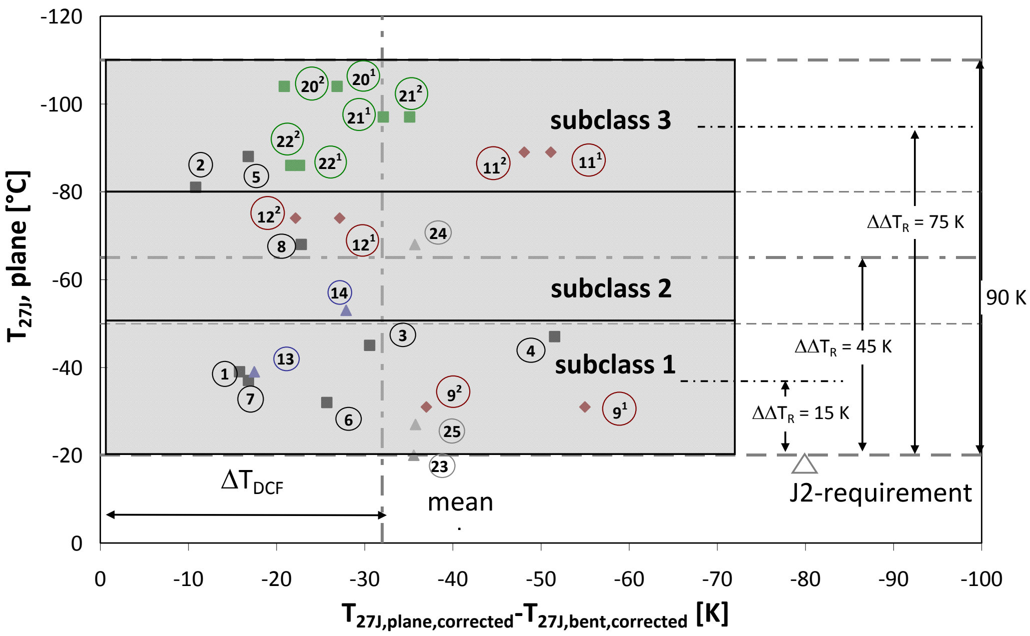


Figure 8-11: Introduction of subclasses for toughness properties

(15) The consequences of such subclasses would be as shown in Figure 8-12 with reference to Figure 1-3: Due to different $\Delta\Delta T_R$-values, which represent the distances between the mean value of T_{27J} in the plane area of cross section, the ΔT_{DCF}-values vary between 65 K and 5 K.

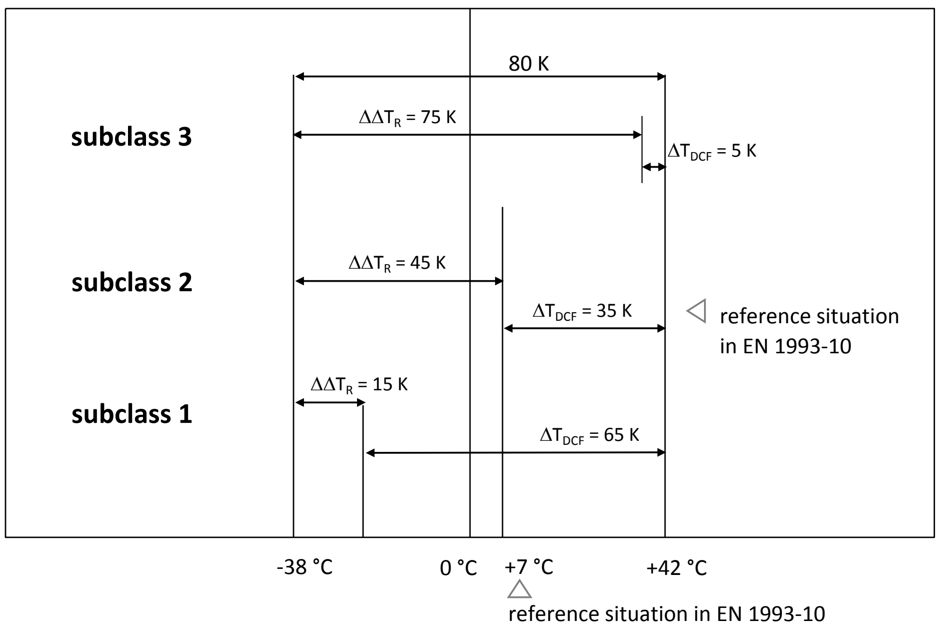


Figure 8-12: ΔT_{DCF}-values in case of introduction of subclasses

(16) Table 8-2 also allows to draw conclusions from the measured and corrected values T_{27J} for bent and aged areas. In Figure 8-13 the relation of

$T_{27J,bent\&aged,corrected}$ and $T_{27J,bent,corrected}$ is plotted. The plot shows that there is almost no negative effect of ageing.

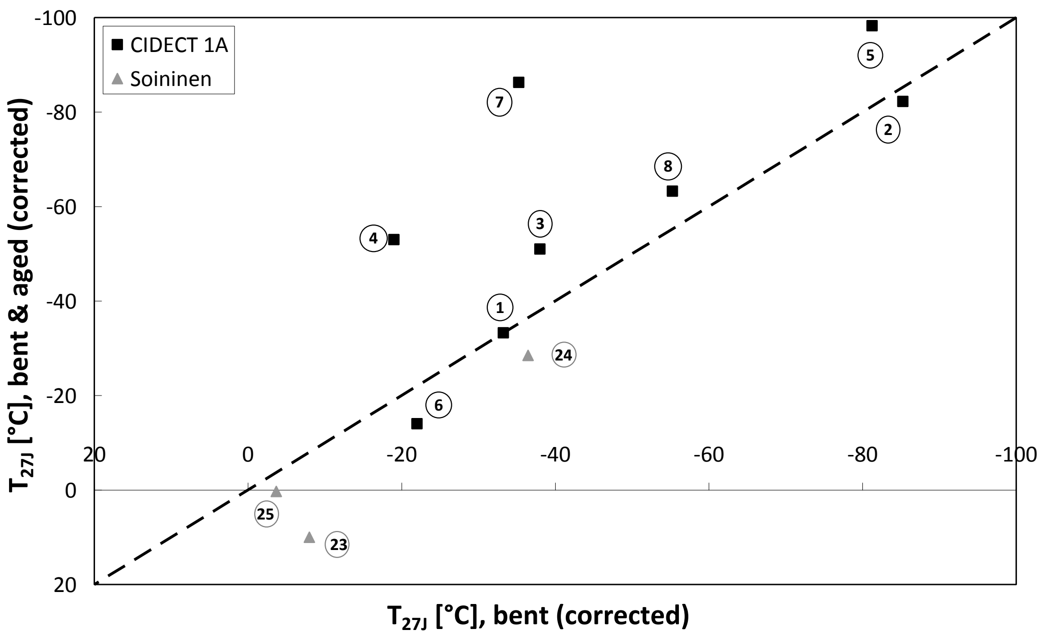


Figure 8-13: Effect of ageing on T_{27J} in the bent zone (related to corrected values)

8.4 Conclusion

(1) As a conclusion from the evaluations of tests with Charpy-V-impact energies carried out for cold-formed hollow rectangular sections with sizes 100x100x8 to 254x254x15,9 made of mainly steels S355J2 the following can be stated:

1. The values ΔT_{DCF} determined by way of calculation from properties of the feed-material (approach no. 1) are approximately the same as those from test evaluations (approach no. 2).
2. The mean value ΔT_{DCF} for the corner-region of rectangular hollow sections with $t \leq 16$ mm and S355J2 is for the full population of tests in the range of ΔT_{DCF} = 35 K. For larger thicknesses and full exploitation of tolerances for radii the value would be ΔT_{DCF} = 45 K, which is the maximum possible value.
3. The aforementioned conclusions hold true if referred to a full population of steels and production methods that fulfil the range of toughness properties -110 °C < T_{27J} < -20 °C equally (scatter of 90 K).
4. A proposal to take profit of good toughness properties of J2-steels from qualified producers would be to subdivide the full population with the scatter band of 90 K into three sub-populations with a scatter band of 90 K/3 =30 K each, see Figure 8-11, by introducing subclasses of toughness properties, that would give different values ΔT_{DCF}, favouring subclass 3 with low values and penalising subclass 1 with high values.

subclass 1: $-50\ °C \leq T_{27J} < -20°C$ -> $\Delta T_{DCF} = 65\ K$

subclass 2: $-80\ °C \leq T_{27J} < -50°C$ -> $\Delta T_{DCF} = 35\ K$

subclass 3: $-110\ °C \leq T_{27J} < -80°C$ -> $\Delta T_{DCF} = 5\ K$

The recommendation in 2. for $\Delta T_{DCF} = 35$ K above would then apply to the medium subclass 2 only, see Figure 8-12.

5. Unfortunately this subclassification which is based on the T_{27J}-values in the plane area of rectangular hollow sections determined according to EN 10219 cannot be substituted a subclassification according to other properties, e.g. the steel grade, steel quality or the chemical compositions of the steel or combinations of them, because there are not clear correlations between toughness performance and these properties for a given steel grade. Therefore a distinction of classes could only be made on the basis of the T_{27J}-values as measured in the plane area (values acc. to EN 10219).

(2) The conclusions made on the basis of test results for a limited test population with regard to sizes and steel grades (see ((1)) also apply to other sizes and steel grades than tested, as approach no. 1 is the relevant and this applies to all sizes and steel grades.

9 Evaluation of test data for circular cold-formed hollow sections and conclusion

(1) Annex A.2 gives KV-values for a single circular hollow section with T_{27J} = -69 °C for steel S355J2H.

(2) The “expected” mean value from Figure 1-3 is

$$T_{27J} - 45\text{K} = -20 - 45 = -65\,^{\circ}\text{C} \qquad \textbf{(9-1)}$$

(3) The test population is not sufficient to draw conclusions.

10 Evaluation of test data for cold-formed and stress relieved hollow sections

(1) Annex A.3 gives KV-values and T_{KV}-values for rectangular cold-formed hollow-sections, which are stress-relieved and listed in Table 10-1.

(2) Figure 10-1 gives the KV_{US}-values versus T_{US} for the plane zones of the sections.

Table 10-1: KV_{US}, T_{US} and T_{27J}-values for cold-formed hollow sections with stress relief

No. of eval-uation	test series	steel grade	test no.	plane			bent			aged		
				KV_{US} [J]	T_{US} [°C]	T_{27J} [°C]	KV_{US} [J]	T_{US} [°C]	T_{27J} [°C]	KV_{US} [J]	T_{US} [°C]	T_{27J} [°C]
1	CIDECT 1B Report	A500B Class H	RHS 305X 305X 12,7	195	+10	-23	145 165	+10 +50	-27 -2	165	-10	-36
3	CIDECT 1B Report	S355J2H	RHS 350X 350X 12,5	320	-20	-74	245 240	0 +10	-74 -30	240	-40	-111

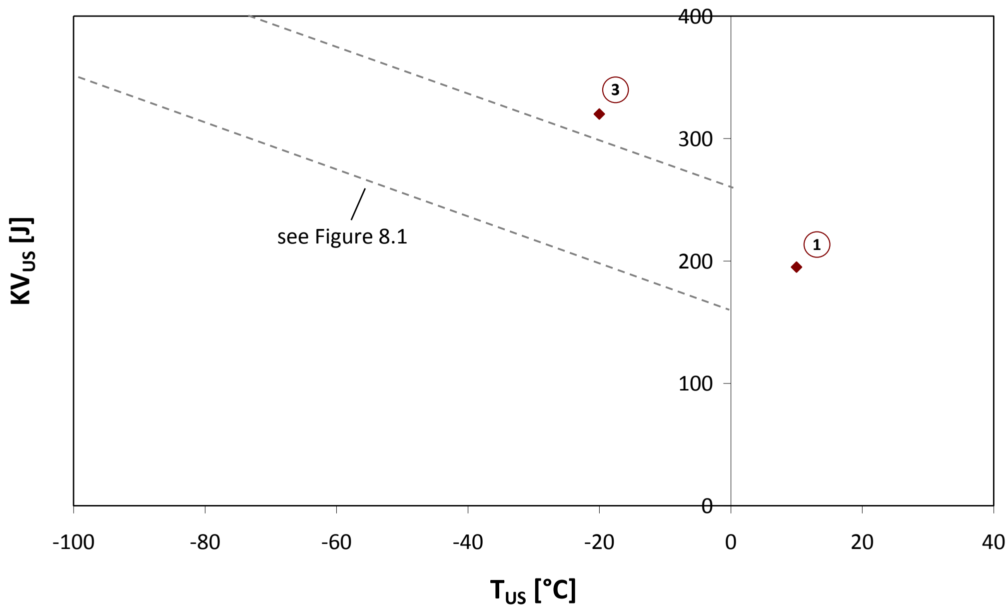


Figure 10-1: Toughness data in the plane region of cold-formed and stress-relieved hollow sections

(3) The relation of T_{27J}-values measured in the plane area and in the bent area is illustrated in Figure 10-2.

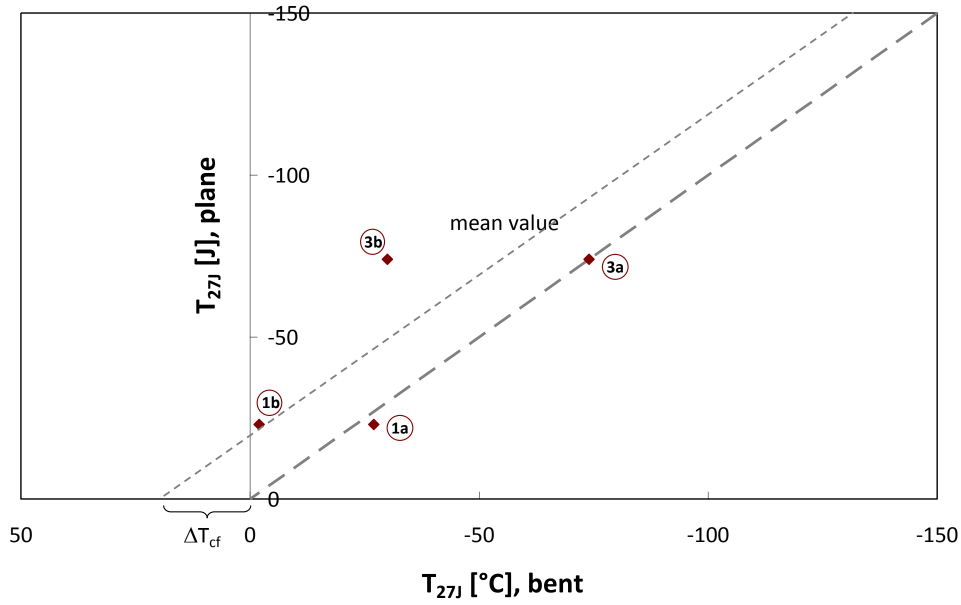


Figure 10-2: Comparison of T_{27J} data in plane and bent areas of cold-formed and stress-relieved hot-rolled hollow sections

(4) A comparison of Figure 10-1 and Figure 10-2 with Figure 8-1 and Figure 8-7 illustrates that the cold-formed and stress-relieved hollow sections can be allocated to cold-formed sections without stress-relief as stress relief (~460 °C) has no effect on the dislocation density.

11 Evaluation of test data for hot-finished hollow sections

11.1 Evaluation method

(1) The method to determine the admissible plate-thickness for hot-finished hollow sections to EN 10210 is based on approach no. 2, comprising the following steps:

1. Toughness-values are determined from standardized transition curves, see section 7.3.2, using Charpy-V-test results documented in Annex A.4. Also estimates of T_{27J}-values from formula (7-3) are indicated.
2. The Charpy V-tests performed in [16] can be taken as representative because the investigation considers hollow sections produced by three different production processes from three different plants.
3. The toughness values in the upper shelf region of the toughness-temperature diagram

   KV_{US}, T_{US}

   and in the transition region

   T_{27J}

   are plotted in the same way as for cold-formed sections, to illustrate the material properties of the test specimens in the flat area and in the corner area.
4. Measured values T_{27J} are compared with the T_{27J}-value specified in EN 10210 to check if the conditions assumed in EN 1993-1-10, see Figure 1-3, for using ΔT_R = -7 K are met.
5. A conclusion for a temperature shift is drawn.

(2) The material data from Annex A.4 are summarized in Table 11-1, that may be compared with Table 8-1 for cold-formed sections.

Table 11-1: Values of upper-shelf characteristics and of T_{27J} as evaluated from measurements, see Annex A.4

No. of eval.	test series	steel grade	prod. method	test no.	location and treatment				location and treatment	
					plane		corner		plane	corner
					KV_{us}	T_{us}	KV_{us}	T_{us}	T_{27J}	T_{27J}
					[J]	[°C]	[J]	[°C]	[°C]	[°C]
1	CIDECT 1B	S355J2H		1B-7	250	30	280[1)] 270[2)]	40[1)] 30[2)]	-80	-83[1)] -74[2)]
2	V & M	S355J2H		Ham 12,5	270	-25	275[1)] 270[2)]	-25[1)] -25[2)]	-118	-118[1)] -119[2)]
3		S355J2H		Ham 16,0	230	-40	210[1)] 240[2)]	-50[1)] -25[2)]	-117	-111[1)] -121[2)]
4		S355J2H		Ham 20,0	260	-25	245[1)] 230[2)]	-60[1)] -30[2)]	-128	-93[1)] -125[2)]
5		S355J2H		D 12,5	260	10	255[1)] 280[2)]	10[1)] 30[2)]	-81	-74[1)] -101[2)]
6		S355J2H		D 16,0	235	10	240[1)] 275[2)]	10[1)] 20[2)]	-81	-82[1)] -80[2)]
7		S355J2H		D 17,5	235	0	225[1)] 270[2)]	5[1)] 10[2)]	-70	-67[1)] -68[2)]
8		S355J2H		D 20,0	260	10	210[1)] 270[2)]	10[1)] 5[2)]	-77	-53[1)] -54[2)]
9		S355J0H		Mh-11,0	240	-10	250[1)] 250[2)]	25[1)] 25[2)]	-93	-95[1)] -101[2)]
10	CIDECT 1B	A53B		1B-8	60	-45			-85	

Note: *OS* *ordinary steel*
TM-FG *thermo-mechanically rolled micro-alloyed fine grain steel*
FG *micro-alloyed fine grain steel*

Index: *1)* *Inner notch*
2) *Outer notch*

11.2 Upper-shelf toughness properties and T_{27J}-values

(1) The presentation of results is made in a similar way as for cold-formed sections.

(2) Figure 11-1 (see Figure 8-1) gives the pairs of values (KV_{US}, T_{US}) for the upper-shelf region for the plane areas. It demonstrates the high quality of steels used for the test specimens with toughness values that are all about on the same.

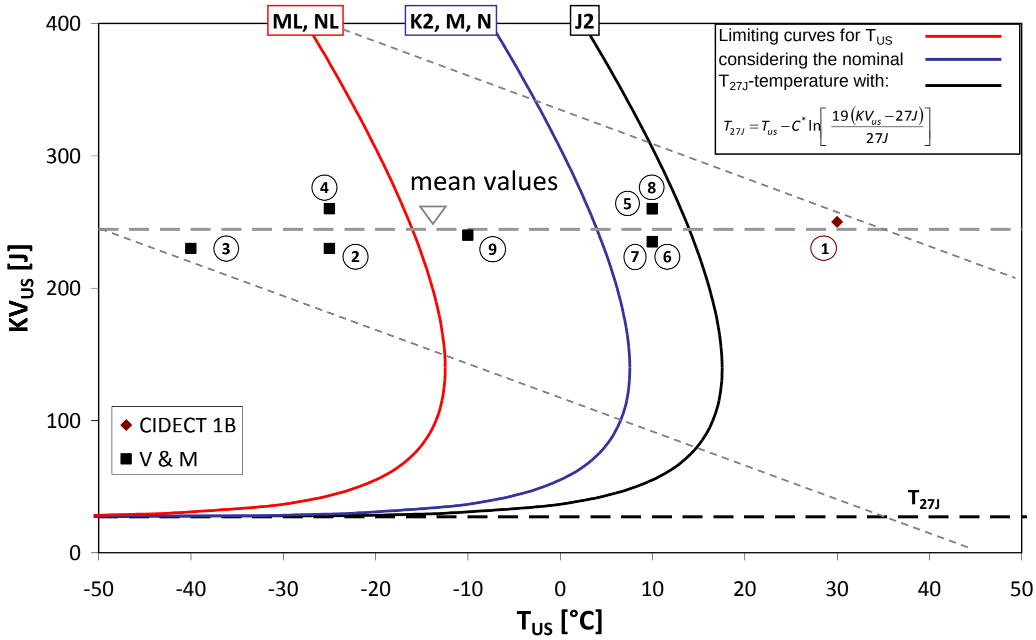


Figure 11-1: Upper-shelf characteristics of steels KV_{US} and T_{US} in hot-finished rectangular hollow sections (data from plane areas)

(3) Figure 11-2 (see Figure 8-2) gives a comparison of upper-shelf values (KV_{US}, T_{US}) in the plane area and the corner area. It is evident that the values in the corner area are about the same as in the plane area.

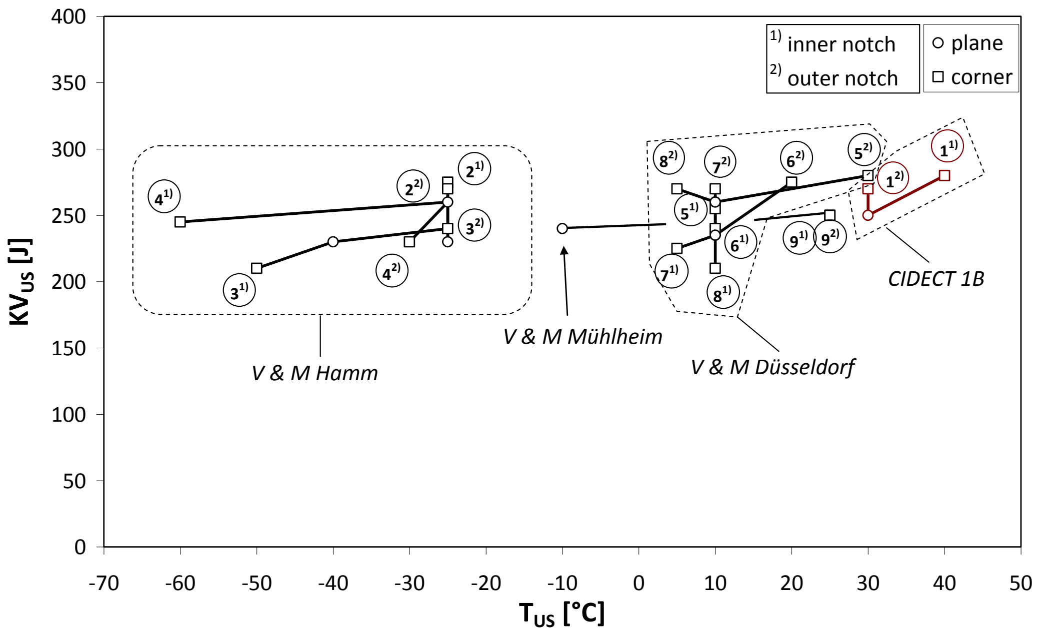


Figure 11-2: Comparison of KV_{US}-values and T_{US}-values of hot-finished rectangular sections in the plane area (○) and corner area (□)

(4) Figure 11-3 (see Figure 8-3) gives from Figure 11-2 the relationship between T_{US} and T_{27J} in the plane area and Figure 11-4 (see Figure 8-4) gives the values T_{US} and T_{27J} for the corner area, which allows to determine a correlation between T_{US} and T_{27J}.

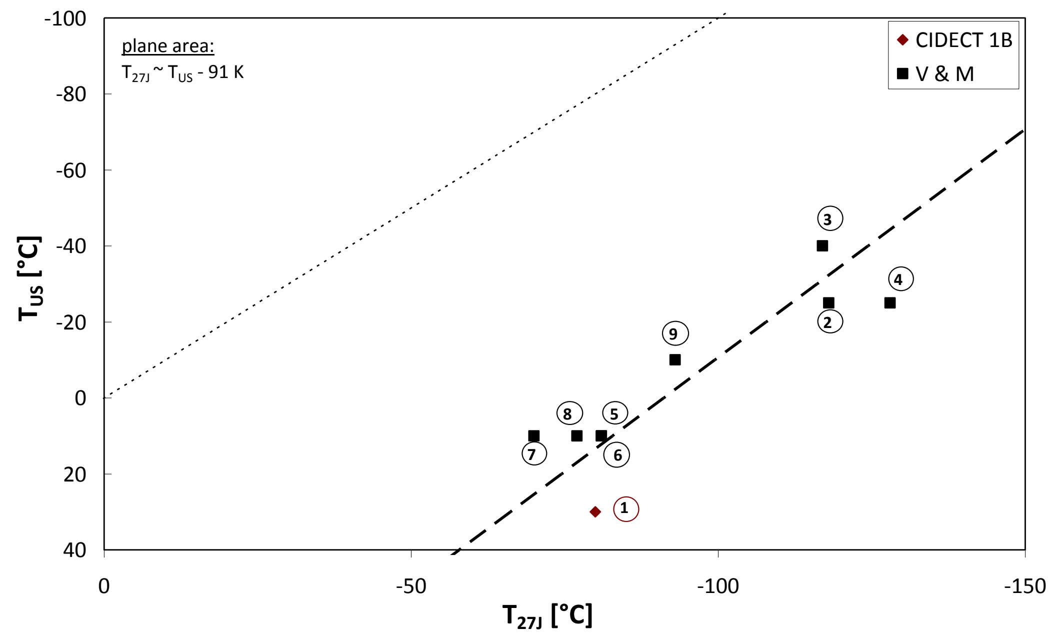


Figure 11-3: Relationship between T_{US} and T_{27J} of hot-finished rectangular sections as measured in the plane area

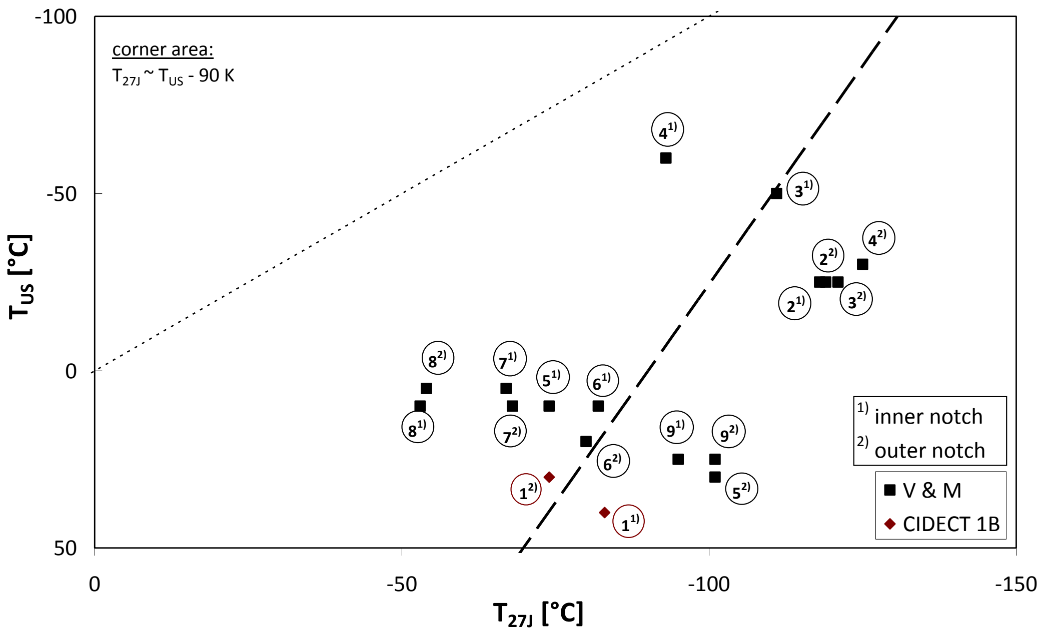


Figure 11-4: Relationship between T_{US} and T_{27J} of hot-finished rectangular sections as measured in the corner area

(5) In Figure 11-5 (see Figure 8-5) the relationship between KV_{US} and T_{27J} in the plane area is given, whereas Figure 11-6 (see Figure 8-6) gives the ratios between KV_{US} in the plane and in the corner area. These values demonstrate almost equal properties without large effects from production.

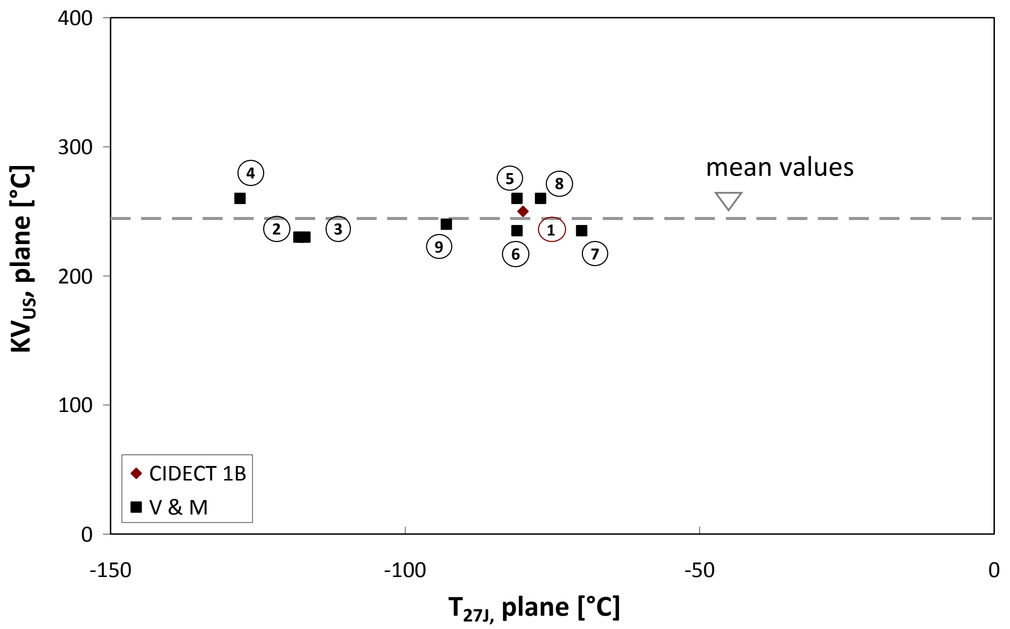


Figure 11-5: Relationship between $KV_{US,plane}$ and T_{27J} of hot-finished rectangular sections in the plane area

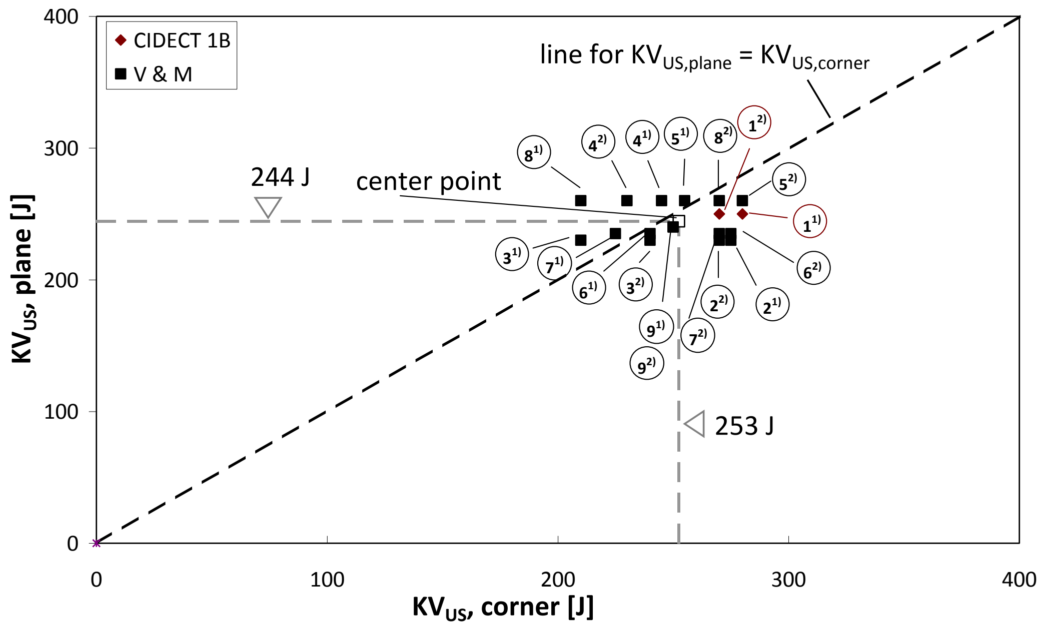


Figure 11-6: Ratios between $KV_{US,plane}$ and $KV_{US,corner}$ of hot-finished rectangular sections

(6) Figure 11-7 (see Figure 8-7) finally gives the ratios between the T_{27J}-values in the plane area and the corner area, where the mean T_{27J} = -94 °C in the plane region corresponds to T_{27J} = -90 °C in the corner region with a small variation of values in the plane and a somewhat larger variation in the corner, all values being far above the requirements.

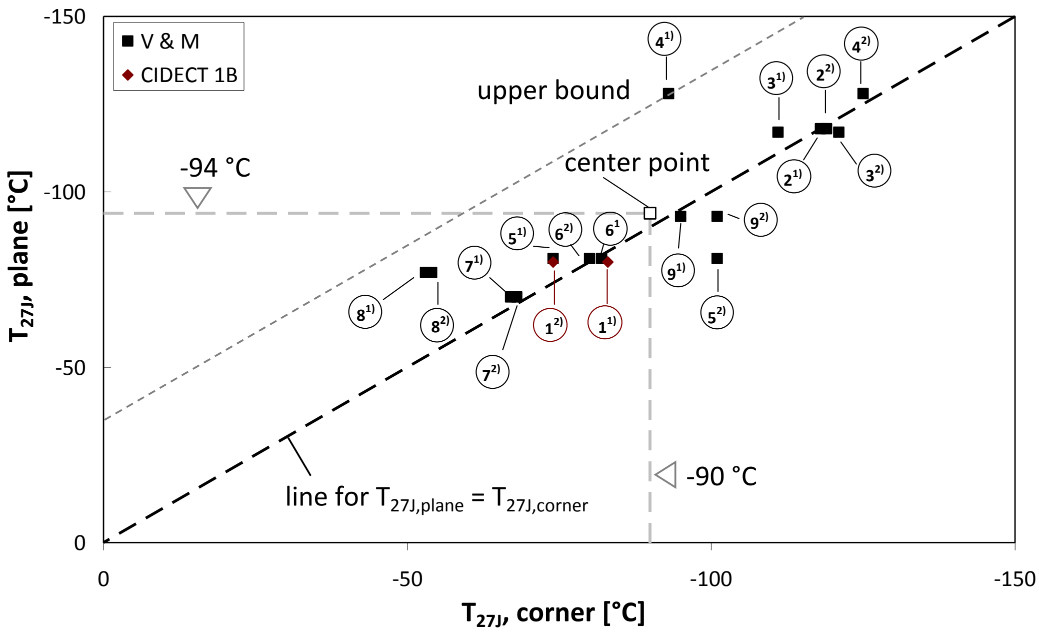


Figure 11-7: Ratios between $T_{27J,plane}$ and $T_{27J,corner}$ of hot-finished rectangular sections

11.3 Conclusions

(1) Figure 11-8 (see Figure 8-10) gives a comparison of $T_{27J,plane}$, which is the reference value according to EN 10210, and $b_i = T_{27J,plane} - T_{27J,corner}$.

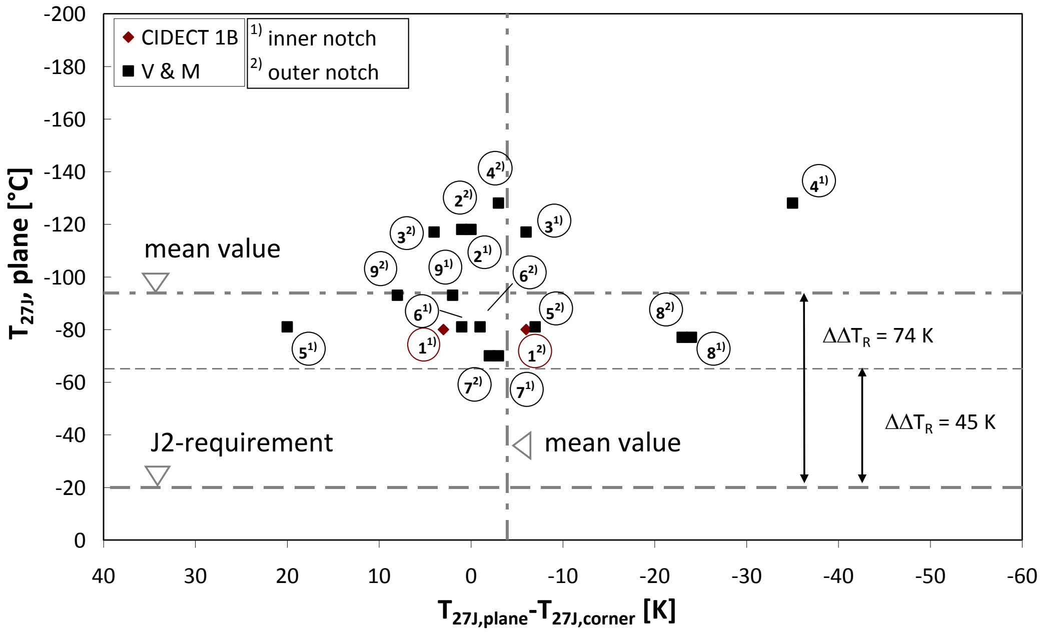


Figure 11-8: Values b_i = $T_{27J,plane}$ - $T_{27J,corner}$ versus $T_{27J,plane}$ measured of hot-finished rectangular sections

(2) The Figure 11-8 demonstrates, that the shift $\Delta\Delta T_R$ is greater than the target value $\Delta\Delta T_R$ = 45 K, see Figure 1-3, so that EN 1993-1-10 can be applied to hot-finished hollow section without any temperature shift from production.

(3) Figure 11-8 also demonstrates, that a division in subclasses of material qualities as indicated in Figure 8-11 and Figure 8-12 would also be applicable, so that the benefit of the "over performance" of the test-specimens in relation to the minimum requirement in EN 10210 could be taken into account in design.

12 Proposal for amendment of EN 1993-1-10

(1) In order to include cold-formed hollow sections into the rules for the choice of steel to avoid brittle fracture in EN 1993-1-10, the following amendment is proposed for EN 1993-1-10 (2005).

(2) Hot-finished hollow sections according to EN 10210-1 are fully covered by EN 1993-1-10 without any temperature shift from production.

(3) This amendment also applies to any cold-formed cross-section, e.g. those according to EN 1993-1-3.

(4) The amendment of EN 1993-1-10 covers the steels in EN 1993-1-12 as well, so that with the amendment of EN 1993-1-10 separate rules for choice of material in EN 1993-1-12 could be eliminated.

(5) The proposal for the amendment contains the following:

1. Table 2.1 in section 2.3.2 of EN 1993-1-10 should be replaced by the following new Table 12-1.

Table 12-1: Choice of steel material to avoid brittle fracture (table 2.1 of EN 1993-1-10 extended, absolute values)

Reference temperature T_{Ed} [°C] — $\sigma_{Ed} = 0{,}75\ f_y(t)$

Steel grade	Sub-grade	Charpy energy CVN at T [°C]	J_{min}	10	0	-10	-20	-30	-40	-50	-60	-70	-80	-90	-100	-110	-120
S235	JR	+20	27	62	51	43	36	30	25	21	18	16	14	12	11	10	9
	J0	0	27	89	74	62	51	43	36	30	25	21	18	16	14	12	11
	J2	-20	27	126	106	89	74	62	51	43	36	30	25	21	18	16	14
S275	JR	+20	27	54	45	37	31	26	22	18	15	13	11	10	9	8	7
	J0	0	27	78	65	54	45	37	31	26	22	18	15	13	11	10	9
	J2	-20	27	112	94	78	65	54	45	37	31	26	22	18	15	13	11
	M, N	-20	40	132	111	93	77	64	53	44	37	31	25	21	18	15	13
	ML, NL	-50	27	185	158	134	112	94	78	65	54	45	37	31	26	22	18
S355	JR	+20	27	43	35	29	24	20	16	14	11	10	8	7	6	5	5
	J0	0	27	63	52	43	35	29	24	20	16	14	11	10	8	7	6
	J2	-20	27	92	76	63	52	43	35	29	24	20	16	14	11	10	8
	K2,M,N	-20	40	109	91	75	62	51	42	35	28	23	19	16	13	11	9
	ML, NL	-50	27	155	131	110	92	76	63	52	43	35	29	24	20	16	14
S420	M, N	-20	40	95	79	65	53	44	36	29	24	19	16	13	11	9	7
	ML, NL	-50	27	137	115	96	80	66	54	44	36	29	24	20	16	13	11
S460	Q	-20	30	77	63	52	42	34	28	23	18	15	12	10	8	7	6
	M, N	-20	40	88	73	60	49	40	32	26	21	17	14	12	9	8	6
	QL	-40	30	112	93	77	63	52	42	34	28	23	18	15	12	10	8
	ML, NL	-50	27	128	107	89	73	60	49	40	33	27	22	18	14	12	10
	QL1	-60	30	157	133	112	93	77	63	52	42	34	28	23	18	15	12
S690	Q	0	40	39	31	25	20	16	13	10	8	6	5	3	2	-	-
	Q	-20	30	52	42	34	27	21	17	13	11	8	7	5	4	2	1
	QL	-20	40	60	48	39	31	25	20	16	13	10	8	6	5	3	2
	QL	-40	30	78	64	52	42	34	27	21	17	13	11	8	7	5	4
	QL1	-40	40	89	73	60	48	39	31	25	20	16	13	10	8	6	5
	QL1	-60	30	113	94	78	64	52	42	34	27	21	17	13	11	8	7

Reference temperature T_{Ed} [°C] — $\sigma_{Ed} = 0{,}50\ f_y(t)$

Steel grade	Sub-grade	Charpy energy CVN at T [°C]	J_{min}	10	0	-10	-20	-30	-40	-50	-60	-70	-80	-90	-100	-110	-120
S235	JR	+20	27	90	77	65	55	47	41	35	31	27	24	21	19	18	16
	J0	0	27	125	106	90	77	65	55	47	41	35	31	27	24	21	19
	J2	-20	27	169	146	125	106	90	77	65	55	47	41	35	31	27	24
S275	JR	+20	27	81	69	58	49	42	36	31	27	24	21	18	17	15	14
	J0	0	27	113	96	81	69	58	49	42	36	31	27	24	21	18	17
	J2	-20	27	156	133	113	96	81	69	58	49	42	36	31	27	24	21
	M, N	-20	40	179	154	132	112	95	81	68	58	49	42	36	31	27	23
	ML, NL	-50	27	199	199	181	156	133	113	96	81	69	58	49	42	36	31
S355	JR	+20	27	68	57	48	40	34	29	25	21	18	16	14	13	11	10
	J0	0	27	96	80	68	57	48	40	34	29	25	21	18	16	14	13
	J2	-20	27	133	113	96	80	68	57	48	40	34	29	25	21	18	16
	K2,M,N	-20	40	155	132	112	95	80	67	56	47	40	34	28	24	21	18
	ML, NL	-50	27	199	181	156	133	113	96	80	68	57	48	40	34	29	25
S420	M, N	-20	40	139	118	99	83	70	58	49	41	34	29	24	20	17	15
	ML, NL	-50	27	190	164	140	119	100	84	71	59	49	41	34	29	24	21
S460	Q	-20	30	116	98	82	68	57	47	39	33	27	23	19	16	14	12
	M, N	-20	40	130	110	93	78	65	54	45	37	31	26	22	18	16	14
	QL	-40	30	160	137	116	98	82	68	57	47	39	33	27	23	19	16
	ML, NL	-50	27	180	155	132	111	94	78	65	54	45	38	31	26	22	19
	QL1	-60	30	199	186	160	137	116	98	82	68	57	47	39	33	27	23
S690	Q	0	40	65	54	44	36	30	24	20	16	13	11	9	8	6	5
	Q	-20	30	84	69	57	47	38	31	26	21	17	14	12	10	8	7
	QL	-20	40	95	79	65	54	44	36	30	24	20	16	13	11	9	8
	QL	-40	30	120	100	84	69	57	47	38	31	26	21	17	14	12	10
	QL1	-40	40	135	114	95	79	65	54	44	36	30	24	20	16	13	11
	QL1	-60	30	166	142	120	100	84	69	57	47	38	31	26	21	17	14

Reference temperature T_{Ed} [°C] — $\sigma_{Ed} = 0{,}25\ f_y(t)$

Steel grade	Sub-grade	Charpy energy CVN at T [°C]	J_{min}	10	0	-10	-20	-30	-40	-50	-60	-70	-80	-90	-100	-110	-120
S235	JR	+20	27	134	116	101	88	77	67	59	53	47	42	39	35	33	31
	J0	0	27	176	154	134	116	101	88	77	67	59	53	47	42	39	35
	J2	-20	27	199	199	176	154	134	116	101	88	77	67	59	53	47	42
S275	JR	+20	27	126	109	95	82	71	62	55	49	43	39	35	32	30	28
	J0	0	27	167	145	126	109	95	82	71	62	55	49	43	39	35	32
	J2	-20	27	199	191	167	145	126	109	95	82	71	62	55	49	43	39
	M, N	-20	40	199	199	189	165	144	125	108	94	81	71	62	55	48	43
	ML, NL	-50	27	229	202	199	199	191	167	145	126	109	95	82	71	62	55
S355	JR	+20	27	112	97	83	72	62	54	47	42	37	33	30	27	25	23
	J0	0	27	150	130	112	97	83	72	62	54	47	42	37	33	30	27
	J2	-20	27	198	173	150	130	112	97	83	72	62	54	47	42	37	33
	K2,M,N	-20	40	199	197	172	149	129	111	96	83	71	62	54	47	41	37
	ML, NL	-50	27	210	199	199	198	173	150	130	112	97	83	72	62	54	47
S420	M, N	-20	40	199	183	159	138	118	102	87	75	64	55	48	42	37	33
	ML, NL	-50	27	199	199	199	185	160	139	119	103	88	75	65	56	48	42
S460	Q	-20	30	183	159	137	118	101	86	74	63	54	47	41	36	31	28
	M, N	-20	40	199	176	152	131	113	96	82	71	61	52	45	39	34	30
	QL	-40	30	199	199	183	159	137	118	101	86	74	63	54	47	41	36
	ML, NL	-50	27	199	199	199	177	153	132	114	97	83	71	61	53	45	39
	QL1	-60	30	222	199	199	199	183	159	137	118	101	86	74	63	54	47
S690	Q	0	40	120	102	87	73	62	52	44	38	32	28	24	21	18	16
	Q	-20	30	147	126	107	91	77	65	55	46	39	34	29	25	22	19
	QL	-20	40	164	141	120	102	87	73	62	52	44	38	32	28	24	21
	QL	-40	30	197	171	147	126	107	91	77	65	55	46	39	34	29	25
	QL1	-40	40	199	189	164	141	120	102	87	73	62	52	44	38	32	28
	QL1	-60	30	199	199	197	171	147	126	107	91	77	65	55	46	39	34

reference temperature

for hot-finished sections T_{Ed}

for cold-formed sections: $T^*_{Ed} = T_{Ed} + \Delta T_{cf}$

Note: *The values in this table are for some parameters slightly different to those given in Table 2.1 of EN 1993-1-10. In a future revision of Table 2.1 of EN 1993-1-10 the values of Table 12-1 could be adopted.*

2. In 2.3.1 General, clause (2), formula (2.4) should read

   $\Delta T_{cf} = -3 \times \varepsilon_{cf}$ [°C], however $\Delta T_{cf} \geq -45$ °C (2.4)

3. In 2.3.1 – General, clause (2) the following notes should be inserted after formula (2.4):

   Note 1:

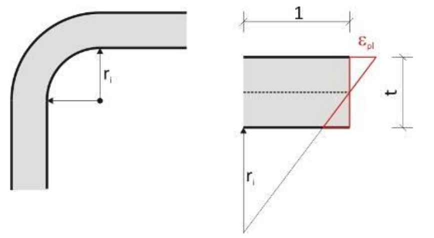
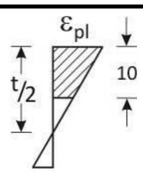
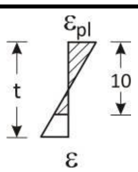
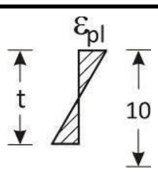
   (1) *For <u>circular cold-formed hollow sections according to EN 10219 and other cold-formed sections to EN 1993-1-3</u> the following adjustment may be used due to cold-forming effects:*

   $\Delta T_{cf} = -3 \cdot \varepsilon_{eff}$ *[K]* *for* $\varepsilon_{eff} > 2$ *%*

   where ε_{eff} *is the average value of plastic strain in the net section of the Charpy-V-test-specimen with longitudinal position in the bent wall. The value depends on the wall thickness and the inner radius* r_i*.*

   (2) *Table 2.2 gives the relationship between the radius of the cold bend and the maximum value of plastic strain* ε_{pl} *and also the value* ε_{eff} *for different wall thickness t.*

Table 2.2: Definition of ε_{pl} and ε_{eff} for radius r_i of cold bend

Determination of maximum plastic strain ε_{pl}		
		$\varepsilon_{pl} = \dfrac{t}{2r_i + t}$
Determination of effective strain ε_{eff}		
t [mm]	ε_{pl}*-distribution*	ε_{eff}
≥ 20		$\varepsilon_{pl}\left(1-\dfrac{10}{t}\right)$
< 20 ≥ 10		$\dfrac{\varepsilon_{pl}}{2}\left(\dfrac{t}{20}+\dfrac{(20-t)^2}{20t}\right)$
< 10		$\dfrac{\varepsilon_{pl}}{2}\dfrac{t}{10}$

(3) *As a conclusion from the calculation method given in (1) and (2) for $r_i/t > 15$ cold-forming effects due to production may be neglected. The maximum value for ΔT_{cf} may be taken as $\Delta T_{cf} = -20$ K.*

Note 2: *For <u>rectangular hollow sections delivered according to EN 10219</u> the adjustment reads:*

$\Delta T_{cf} = -35$ [K] for $t \leq 16$ mm

$\Delta T_{cf} = -45$ [K] for $t > 16$ mm

unless otherwise determined by tests.

Note 3: *In case of ordering cold-formed rectangular hollow sections made of S355 J2 with a wall thickness $t \leq 16$ mm with the specific requirement of T_{27J}-values as specified by the subclasses 1, 2 or 3 the following adjustment values may be used instead of the adjustment given in Note 2:*

subclass 1	*$-20\ °C \geq T_{27J} > -50\ °C$*	*$\Delta T_{cf} = -65$ K*
subclass 2	*$-50\ °C \geq T_{27J} > -80\ °C$*	*$\Delta T_{cf} = -35$ K*
subclass 3	*$-80\ °C \geq T_{27J}$*	*$\Delta T_{cf} = -5$ K*

4. In 2.3.2 – Determination of maximum permissible values of element thickness - the last sentence “The tabulated values are given in terms of a choice of seven reference temperatures: +10, 0, -10, -20, -30, -40 and -50 °C” should be replaced by the new sentence “The tabulated values are given in terms of a choice of fourteen reference temperatures:
+10, 0, -10, -20, -30, -40, -50, -60, -70, -80, -90, -100, -110 and -120 °C”.

13 References

[1] JRC Scientific and Technical Report: Commentary and worked examples to EN 1993-1-10 “Material toughness and through thickness properties and other toughness oriented rules in EN 1993”, EUR 23510, 2008.

[2] Kühn: Beitrag zur Vereinheitlichung der europäischen Regelungen zur Vermeidung von Sprödbruch. Schriftenreihe Stahlbau-RWTH Aachen, Heft 54, Aachen 2005, Shaker Verlag, ISBN: 3-8322-3901-4, ISSN: 0722-1037, 2005.

[3] Stranghöner, N.: Werkstoffauswahl im Stahlbrückenbau. Forschungsbericht 4/2006, Herausgeber: Deutscher Ausschuss für Stahlbau DASt, Düsseldorf, Stahlbau Verlags- und Service GmbH, 2006, ISBN 978-3-923726-20-2.

[4] EN 10025: Hot Rolled Products of Structural Steels. November 2004.

[5] EN 10210: Hot Finished Structural Hollow Sections of Non-Alloy and Fine Grain Steels. April 2006.

[6] EN 10219: Cold-formed Welded Structural Hollow Sections of Non-Alloy and Fine Grain Steels. April 2006.

[7] ASTM E23: Standard Test Methods for Notched Bar Impact Testing of Metallic Materials. 2007.

[8] ASTM A673/A673M-07: Standard Specification for Sampling Procedure for Impact Testing of Structural Steel. 2007.

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

[10] 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. RFCS-Report EUR 21973, 2006.

[11] Ritakallio, P.: Ruukki Cold-formed Hollow Sections – Grade S355J2H – Random Samples, Private Communication, Rauterruukki Oyj, Confidential Test Data. 2010-04-12.

[12] Soininen, R.: Fracture Behaviour and Assessment of Design Requirements against Fracture in Welded Steel Structures made of Cold-formed Hollow Sections. Tieteellisiä Julkaisuja Research Papers 52, Lappeenranta University of Technology, Lappeenranta, Finland, 1996.

[13] Dagg, H.M., Davis, K., Hicks, J.W.: Charpy Impact Tests on Cold-formed RHS manufactured from continuous cast fully killed steel. Proceedings from the Pacific Structural Steel Conference, Australian Institute of Steel Construction, Queensland, Australia, 1989.

[14] Puthli, R., Herion, S., Boellinghaus, T., Florian, W.: Welding in Cold-Formed Areas of Rectangular Hollow Sections. Draft Final Report on Programme 1A, CIDECT Report 1A-5/04, March 2004.

[15] Kosteski, N., Packer, J.A., Puthli, R.S.: Notch Toughness of Cold-formed Hollow Sections. Final (Revision 2), Report to CIDECT on Programme 1B, CIDECT Report 1B-2/03, October 2003.

[16] Stranghöner, N., Lorenz, Chr., Berg, J.: Zähigkeitsuntersuchungen an warmgefertigten Hohlprofilen. Versuchsbericht für Vallourec & Mannesmann, Düsseldorf, Institut für Metall- und Leichtbau, Universität Duisburg-Essen, 2010

[17] Björk, T.: Ductility and Ultimate Strength of Cold-Formed Rectangular Hollow Sections Welded Joints in Arctic Conditions. IIW Document XV-1256-07.

[18] Arndt, J., Dahl, W.: Untersuchungen zur künstlichen Alterung von schweißgeeigneten Baustählen. Institut für Eisenhüttenkunde der RWTH Aachen, 1994.

[19] Langenberg, P., Buchholz, J, Völling, A., Bleck, W., Balladon, P., Wallin, K., Nevasmaa, P., Laukkanen, A.: QUALYTOUGH - Development of a Fracture Toughness Quality System Tool applicable for Steel Producers and Steel Users of Heavy Plates, Profiles and Weldments. Technical Steel Research, European Commission, Research Fund for Coal and Steel, EUR 22454, 2007.

[20] FITNET – Fitness for Service, Volume I and II, Hrsg. Kocak M., First Edt. January 2008.

[21] Zerbst, U., Schödel, M., Webster, S., Ainsworth, R.: Fitness-for-Service Fracture Assessment of Structures Containing Cracks. A Workbook based on the European SINTAP/FITNET Procedure.ISBN 978-0-08-044947-0, 1st ed, 2007.

Annex A Evaluation of test results

Annex A.1 Evaluation of test results (KV-values) with cold-formed hollow sections (rectangular)

No.		test no.	profile	profile dimensions r_a [mm]	r_i [mm]	t [mm]	r_i/t [-]	steel grade	production method	product standard
1	**CIDECT 1A**	B0121	150x150x8	20,9	12,5	8	1,5	S275J2H	OS	EN 10219
2		A22	100x100x8	21,9	12,6	8	1,58	S355J2H	TM-FG	
3		A32	100x100x10	32,5	23,0	10	2,30	S355J2H	TM-FG	
4		B32	100x100x10	24,6	12,0	10	1,20	S355J2H	FG	
5		A0221	150x150x8	21,0	13,4	8	1,67	S355J2H	TM-FG	
6		B0261	150x150x10	25,5	14,9	10	1,49	S355J2H	FG	
7		B23	100x100x8	18,0	12,8	8	1,50	S460MLH	TM-FG	
8		B0321	150x150x8	19,8	12,6	8	1,58	S460MLH	TM-FG	
9	**CIDECT 1B**	1B-1	254x254x15,9	31,8	15,9	15,9	1,00	A500C	OS	ASTM A500-00 class C
10		1B-2	102x102x12,7	25,4	12,7	12,7	1,00	A500C	OS	
11		1B-3	250x250x12,5	37,5	25,0	12,5	2,00	S355J2H	TM-FG	EN 10219
12		1B-4	255x255x8,4	16,0	7,9	8,4	0,95	A53B		ASTM A53/ A 53 M-0
13	**Dagg**	Dagg-1	203x203x9,5	19,1	9,5	9,5	1,00			
14		Dagg-2	76x76x6,3	12,7	6,4	6,3	1,01			
	Ruukki		220x220x9,5	25,0	12,5	12,5	1,00	S355J2H		EN 10219
19		Ruukki-1	150x150x12,5	37,5	25,0	12,5	2,00	S355J2H	TM-FG	
			250x250x10	30,0	20,0	10	2,00	S355J2H		
20		Ruukki-2	300x100x8	20,0	12,0	8	1,50	S355J2H	TM-FG	
21		Ruukki-3	250x250x12,5	37,5	25,0	12,5	2,00	S355J2H	TM-FG	
22		Ruukki-4	200x200x12,5	37,5	25,0	12,5	2,00	S355J2H	TM-FG	
23	**Soininen**	Soininen-1	100x100x10	30,0	20,0	10	2,00	S355J2H	OS	EN 10219
24		Soininen-2	150x150x8	20,0	12,0	8	1,50	S355J2H	OS	
25		Soininen-3	200x200x12,4	37,5	25,0	12,5	2,00	S355J2H	OS	

Note 1: *OS* — *ordinary steel*
TM-FG — *thermo-mechanically rolled micro-alloyed fine grain steel*
FG — *micro-alloyed fine grain steel*

Note 2: ▢ *Results of evaluation not considered in conclusions, see Annex A.*

Annex A.1.1 Results from CIDECT report 1A [14]

Sampling:

(1) The position of the sampling layers is given in Figure A1-1. The specimens were taken as near as possible to the surface. Notch position was parallel to the surface. For the aged specimens the notch tip was placed exactly in the HAZ.

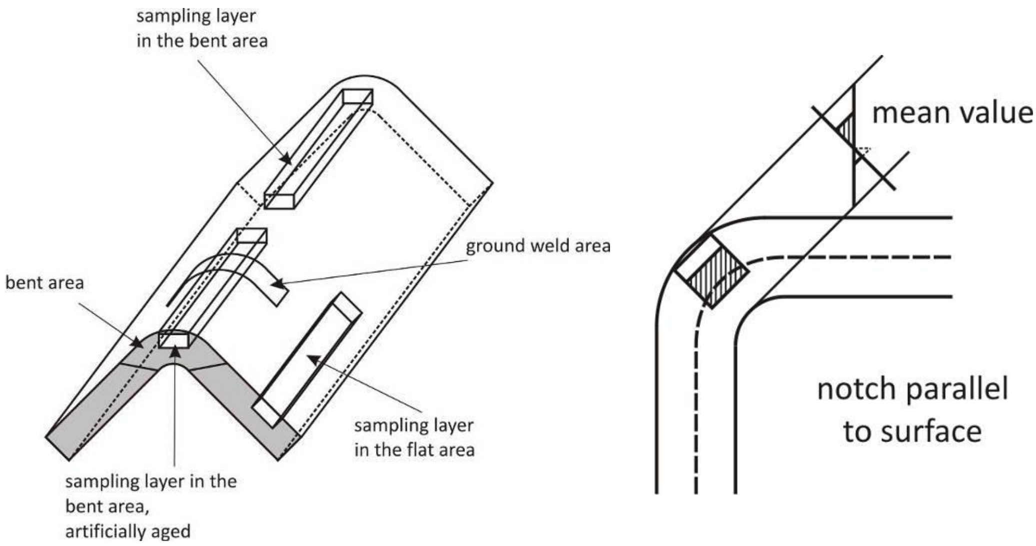


Figure A1-1: Position of Charpy-samples

(2) For evaluation of brittle fracture the notch was prepared in the zone reheated by welding (for determining ageing effects) and located in the HAZ with "removed weld seam", see Figure A1-2.

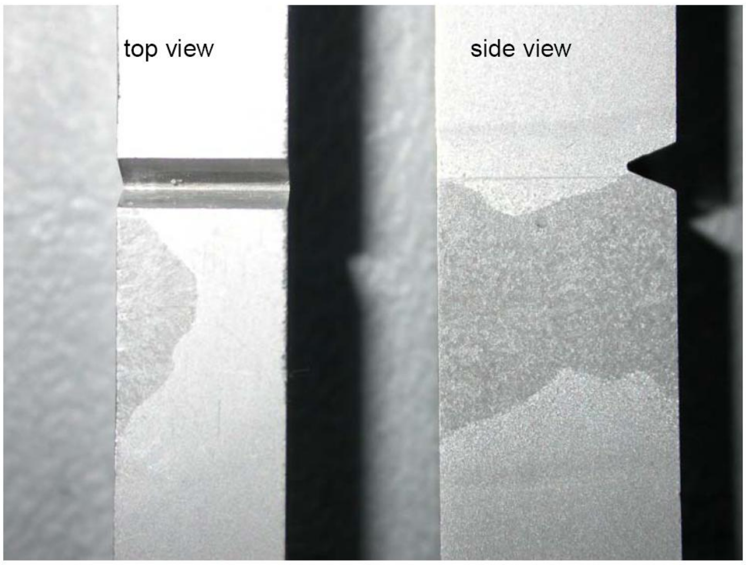


Figure A1-2: Notch position for samples taken from aged sections

No.1 B0121 - RHS 150x150x8 (S275J2H acc. to EN 10219)

Traditional steel from European supplier B

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
150	150	8	20,9	12,0

Geometric dimensions of CVN-specimen

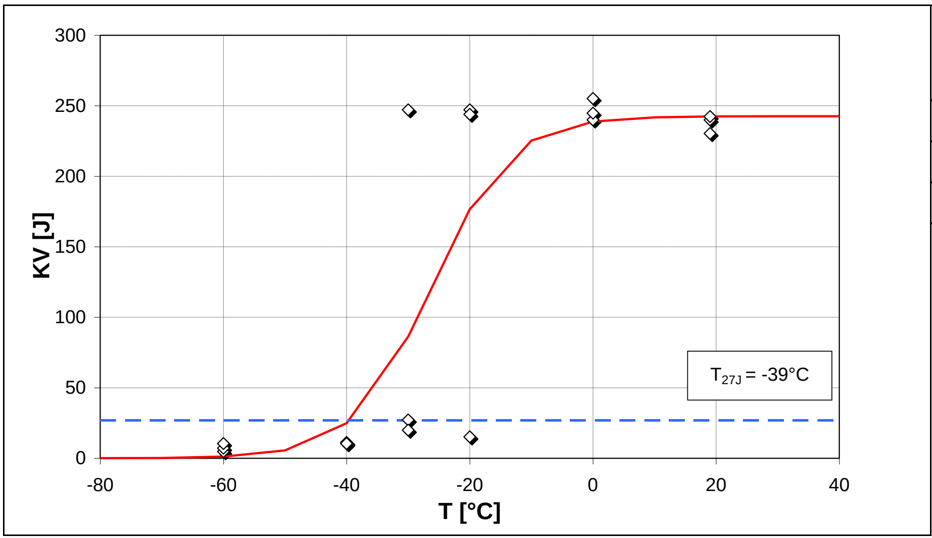
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	8	1,6	0,64	4,80

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,140	0,006	1,128	0,011	0,006	0,047		0,035	0,010	0,006

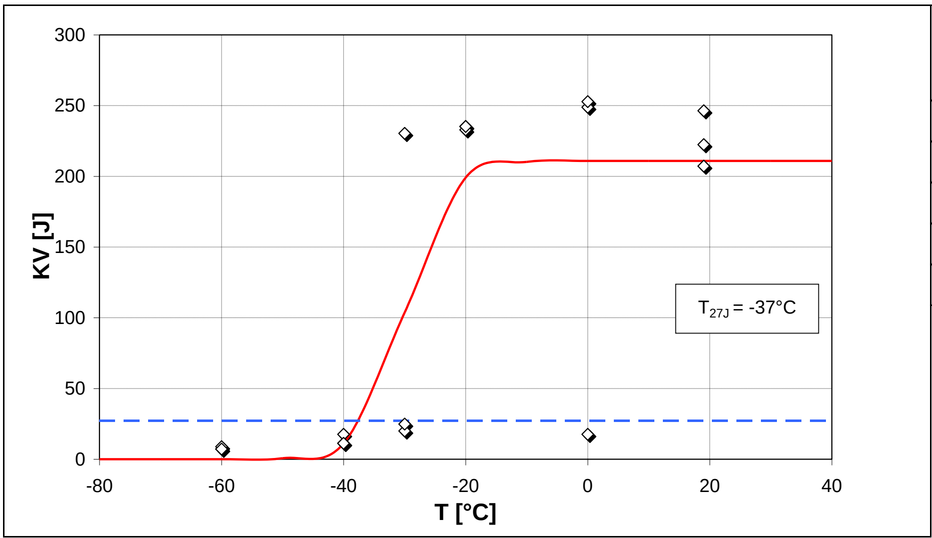
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,024	0,005	0,002	0,011						0,009		

Impact energies



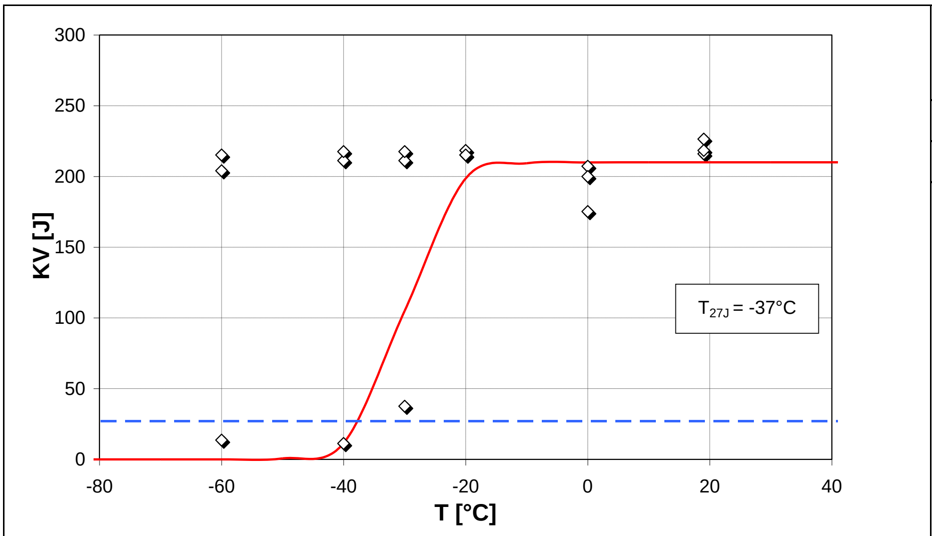
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
20	-24
27	-30

RHS 150x150x8 – plane area



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
18	-32
20	-24
25	-28
18	8

RHS 150x150x8 – bent area



16 J ≤ KV ≤ 67 J	
KV [J]	T27J [°C]
38	-38

RHS 150x150x8 – bent area aged

No.2 A22 - RHS 100x100x8 (S355J2H acc. to EN 10219)

Delivered as grade S355J2H, certified with Charpy-V-testing at -40 °C / 27 J from European supplier A.

Manufactured from micro-alloyed thermo-mechanically rolled fine grain steel.

Concerning Charpy-V-energy these products confirm with S355K2H and S355MH or S420MH.

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
100	100	8	21,9	12,6

Geometric dimensions of CVN-specimen

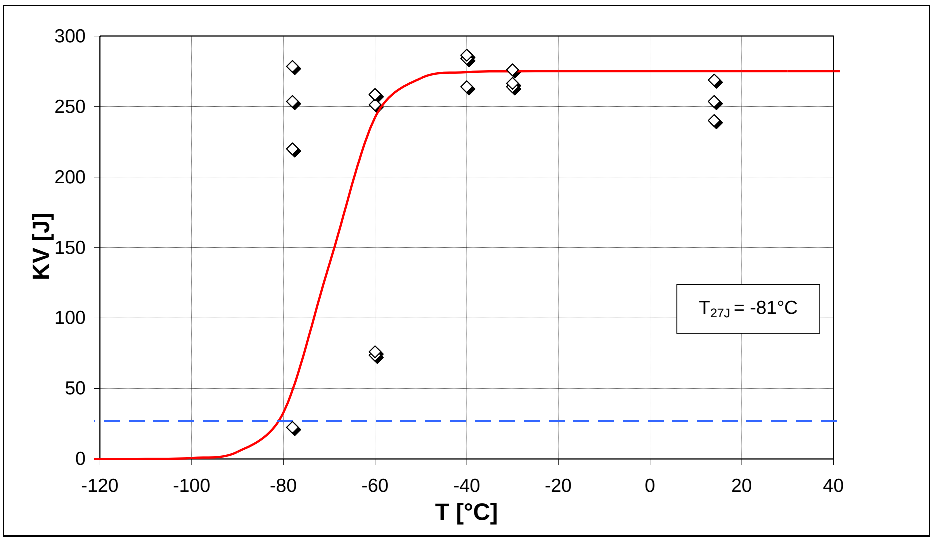
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	8	1,6	0,64	4,80

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,120	0,200	1,470	0,008	0,003	0,018		0,034	0,019	0,002

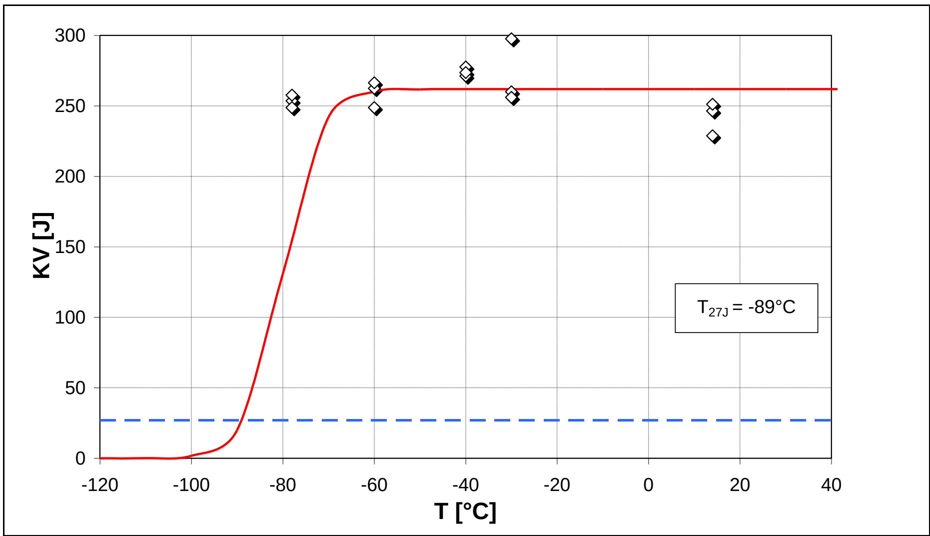
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,033	0,002	0,016	0,003		0,0002			0,004			0,370

Impact energies



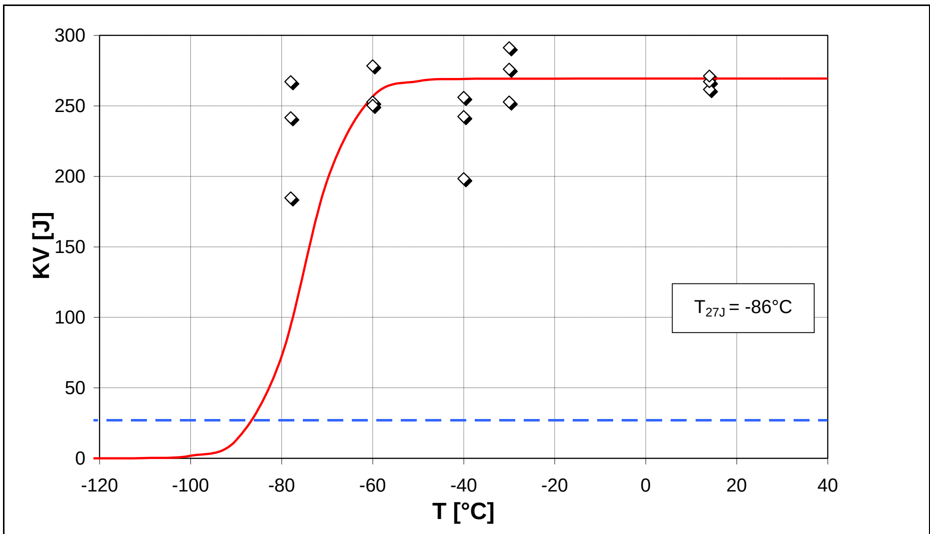
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
22	-74

RHS 100x100x8 – plane area



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 100x100x8 – bent area



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 100x100x8 – bent area aged

No.3 A32 - RHS 100x100x10 (S355J2H acc. to EN 10219)

Delivered as grade S355J2H, certified with Charpy-V-testing at -40 °C / 27 J from European supplier A.

Manufactured from micro-alloyed thermo-mechanically rolled fine grain steel.

Concerning Charpy-V-energy these products confirm with S355K2H and S355MH or S420MH.

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
100	100	10	32,5	23,0

Geometric dimensions of CVN-specimen

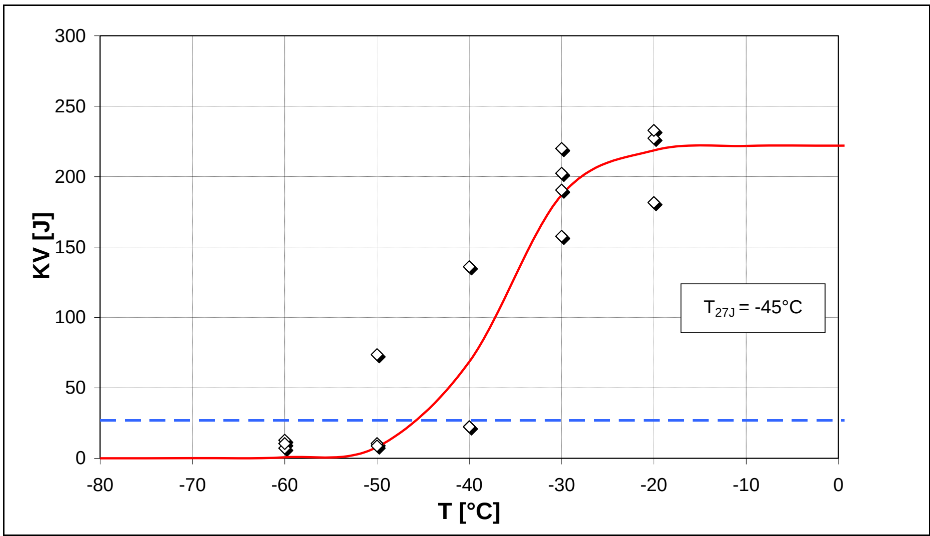
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	8	1,6	0,64	5,80

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,150	0,200	0,600	0,011	0,006	0,015		0,031	0,025	0,004

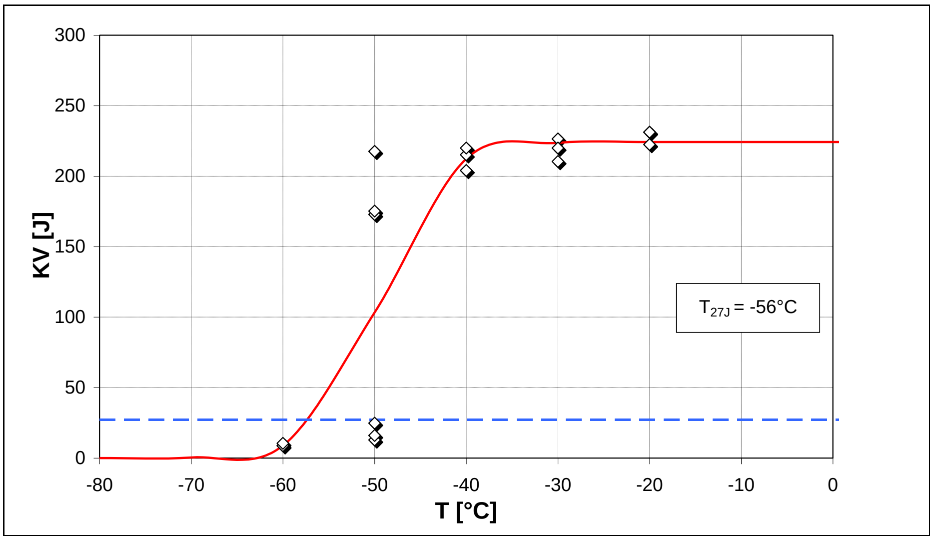
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,035	0,004	0,015	0,002		0,000			0,005			0,250

Impact energies



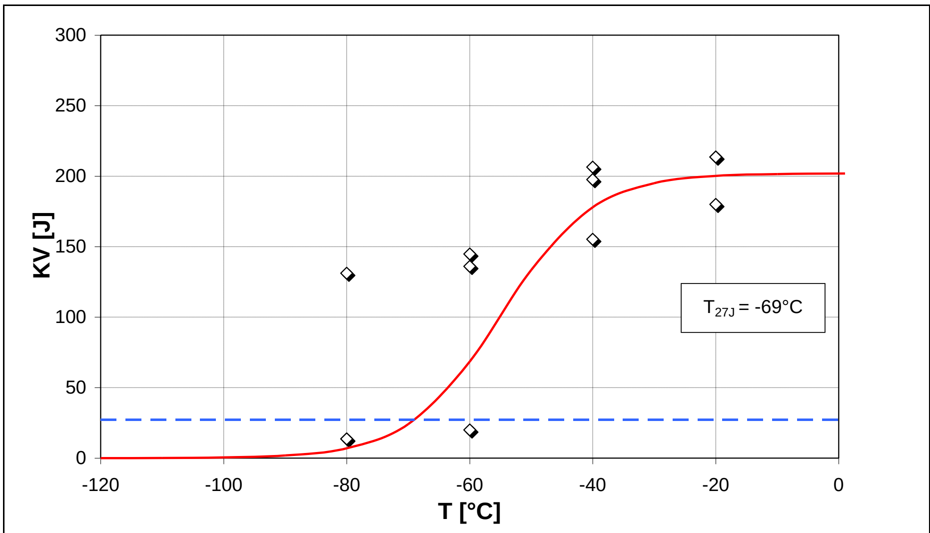
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
22	-36

RHS 100x100x10 – plane area



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
25	-48
16	-40

RHS 100x100x10 – bent area



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
20	-54

RHS 100x100x10 – bent area aged

No.4 B32 - RHS 100x100x10 (S355J2H acc. to EN 10219)

Delivered as grade S355J2H from European supplier B.

These are micro-alloyed fine grain steels as shown by the chemistry.

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
100	100	10	24,6	12,0

Geometric dimensions of CVN-specimen

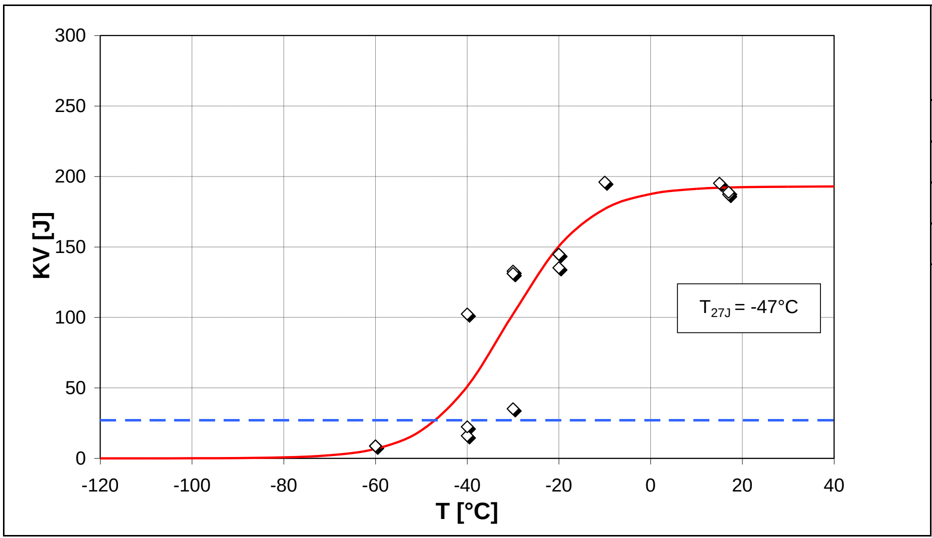
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	8	1,6	0,64	5,80

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,134	0,177	1,433	0,010	0,006	0,045		0,027	0,002	0,005

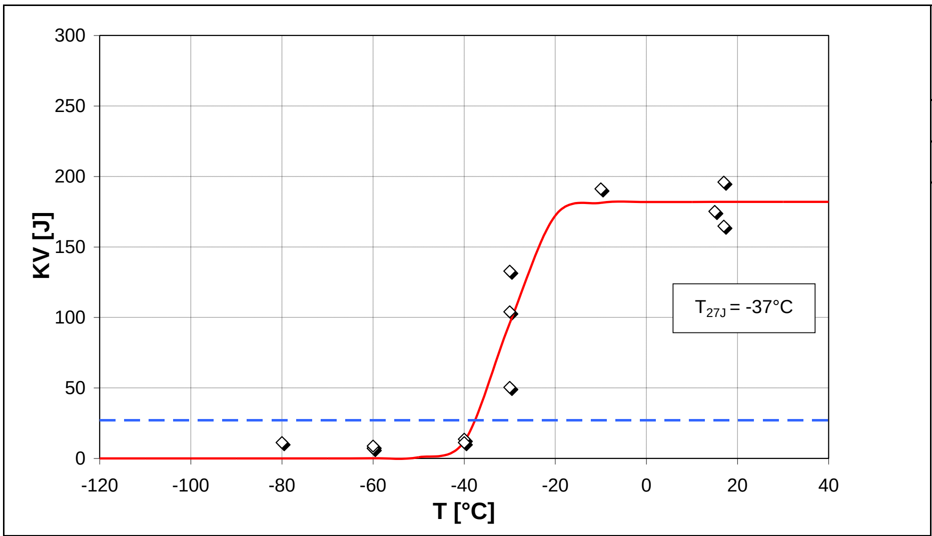
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,024	0,005	0,004	0,021						0,009		

Impact energies



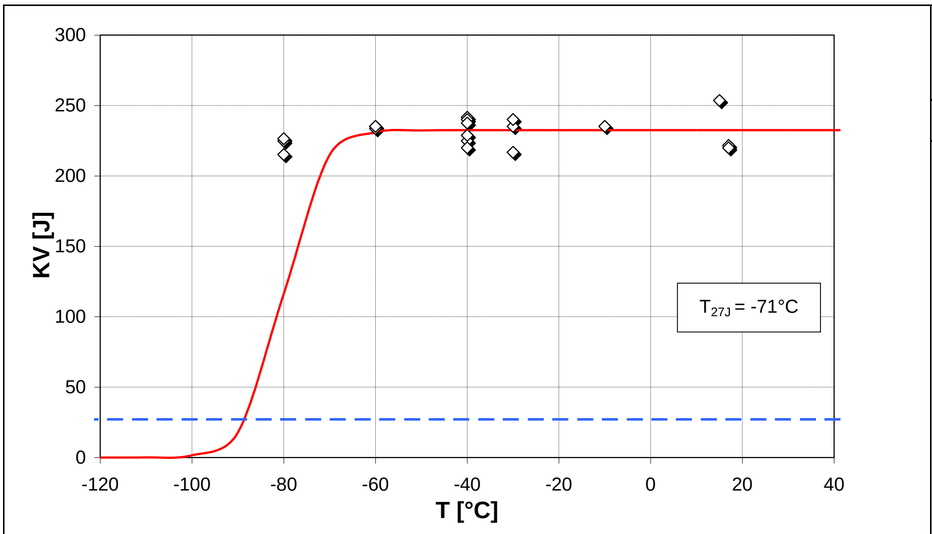
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
16	-30
22	-36
35	-36

RHS 100x100x10 – plane area



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
50	-46

RHS 100x100x10 – bent area



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 100x100x10 – bent area aged

No.5 A0221 - RHS 150x150x8 (S355J2H acc. to EN 10219)

Delivered as grade S355J2H, certified with Charpy-V-testing at -40 °C / 27 J from European supplier A.

Manufactured from micro-alloyed thermo-mechanically rolled fine grain steel.

Concerning Charpy-V-energy these products confirm with S355K2H and S355MH or S420MH.

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
150	150	8	21,0	13,4

Geometric dimensions of CVN-specimen

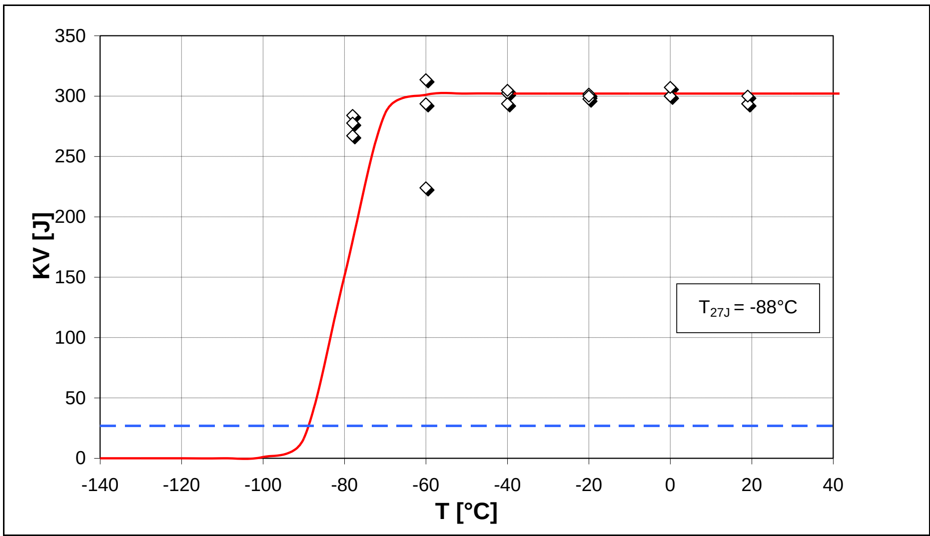
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	8	1,6	0,64	4,80

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,090	0,210	1,460	0,010	0,003	0,017		0,033	0,019	0,000
0,080	0,220	1,520	0,009	0,002	0,023		0,036	0,022	0,002

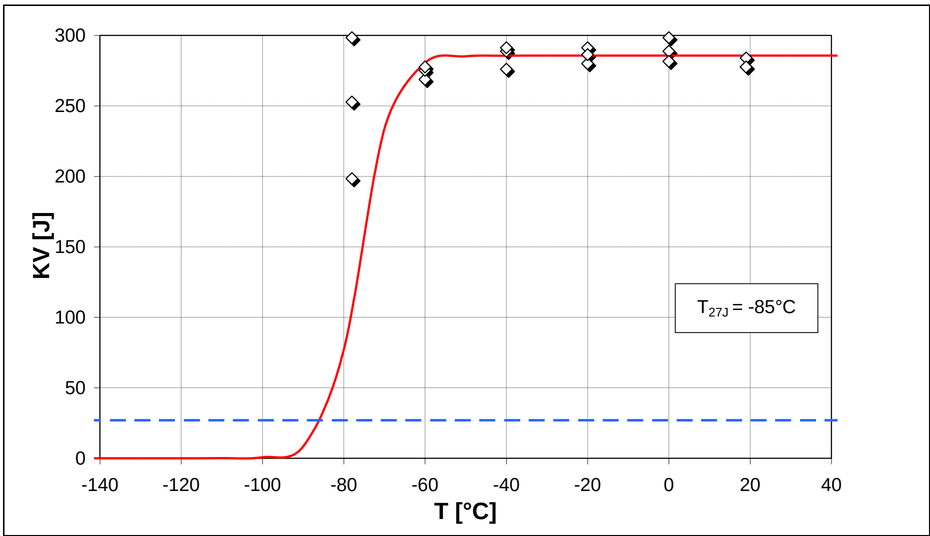
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,035	0,005	0,016	0,014		0,0001			0,004			0,340
0,037	0,006	0,017	0,015		0,0002			0,003			0,350

Impact energies



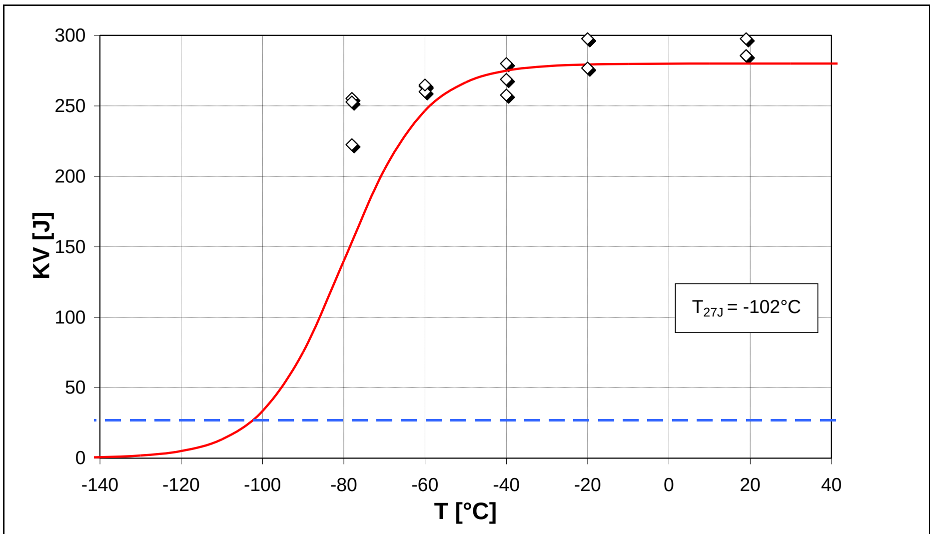
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 150x100x8 – plane area



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 150x150x8 – bent area



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 150x150x8 – bent area aged

No.6 B0261 – RHS 150x150x10 (S355J2H acc. to EN 10219)

Delivered as grade S355J2H from European supplier B.

These are micro-alloyed fine grain steels as shown by the chemistry.

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
150	150	10	25,5	14,9

Geometric dimensions of CVN-specimen

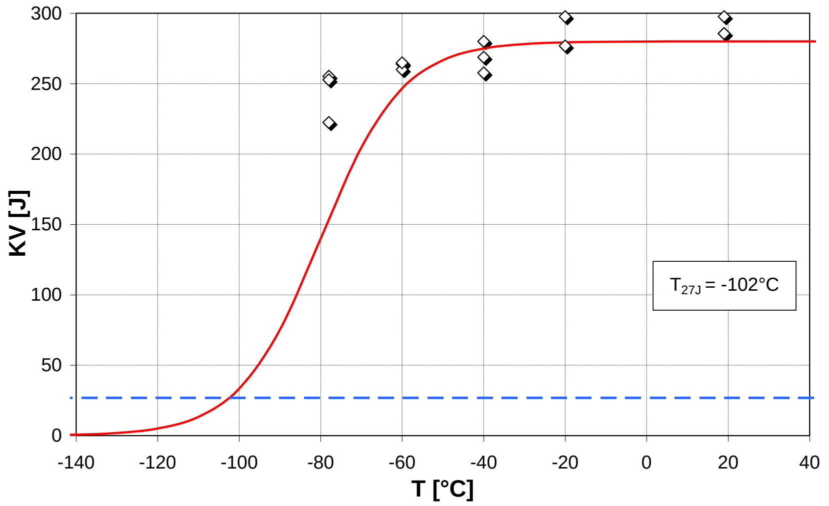
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	8	1,6	0,64	5,80

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,146	0,180	1,461	0,011	0,006	0,025		0,021	0,002	0,003

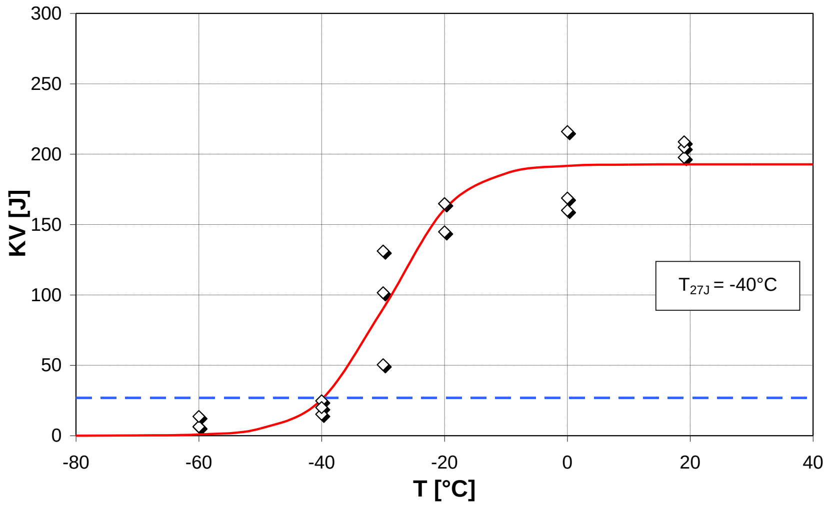
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,008	0,005	0,002	0,021						0,008		

Impact energies



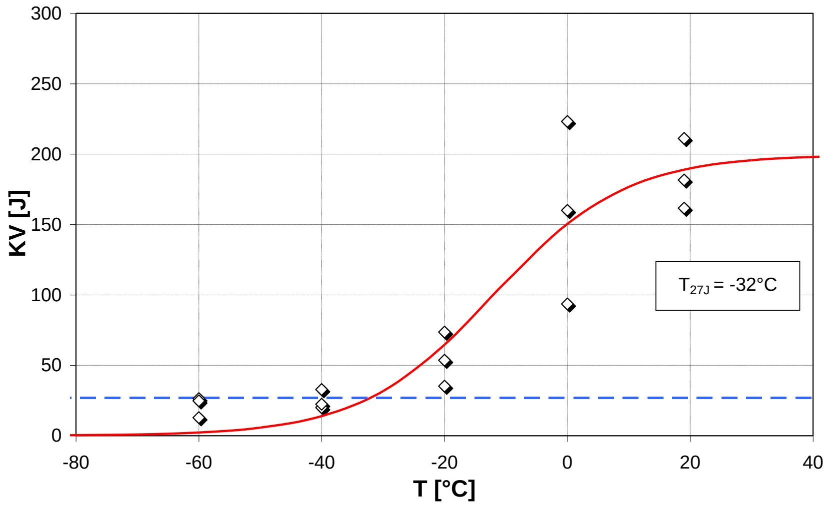
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
47	-54
47	-44
33	-34
24	-27
24	-17
44	-32

RHS 150x150x10 – plane area



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
25	-38
20	-34
50	-46

RHS 150x150x10 – bent area



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
26	-59
25	-58
20	-34
33	-44
22	-36
54	-38
35	-26

RHS 150x150x10 – bent area aged

No.7 B23 - RHS 100x100x8 (S460MLH acc. to EN 10219)

Delivered as grade S460MLH from European supplier B.

Thermo-mechanically rolled micro-alloyed fine grain steels.

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
100	100	8	18,0	12,0

Geometric dimensions of CVN-specimen

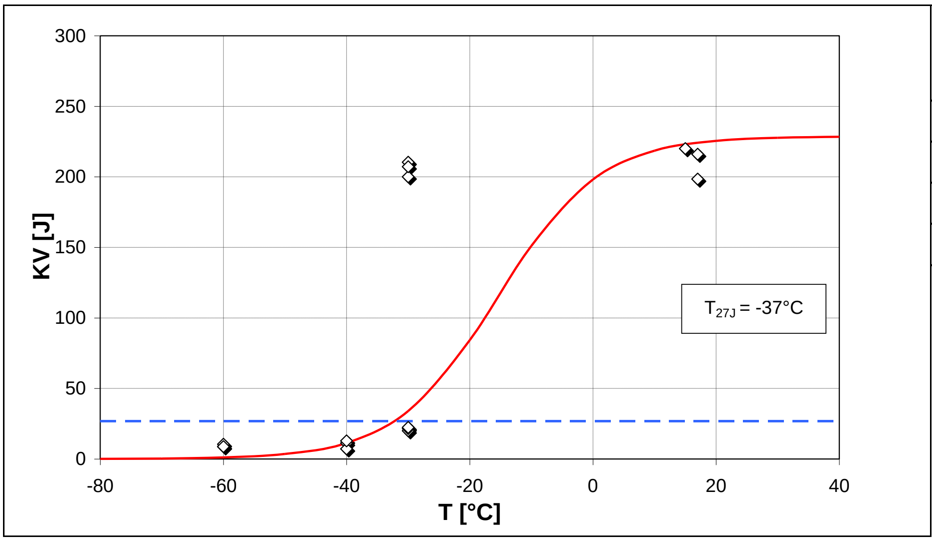
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	8	1,6	0,64	4,80

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,082	0,019	1,106	0,017	0,007	0,015		0,034	0,002	0,003

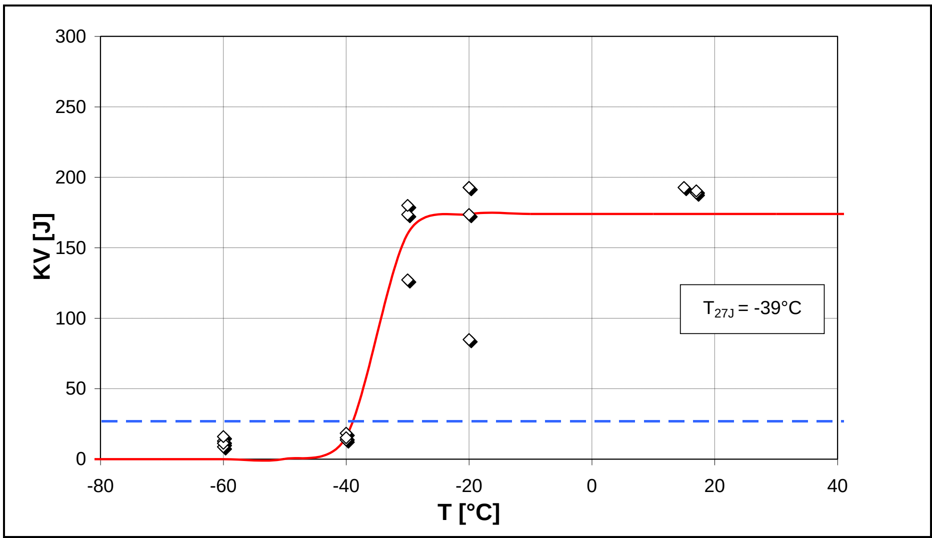
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,002	0,051	0,015	0,062						0,011		

Impact energies



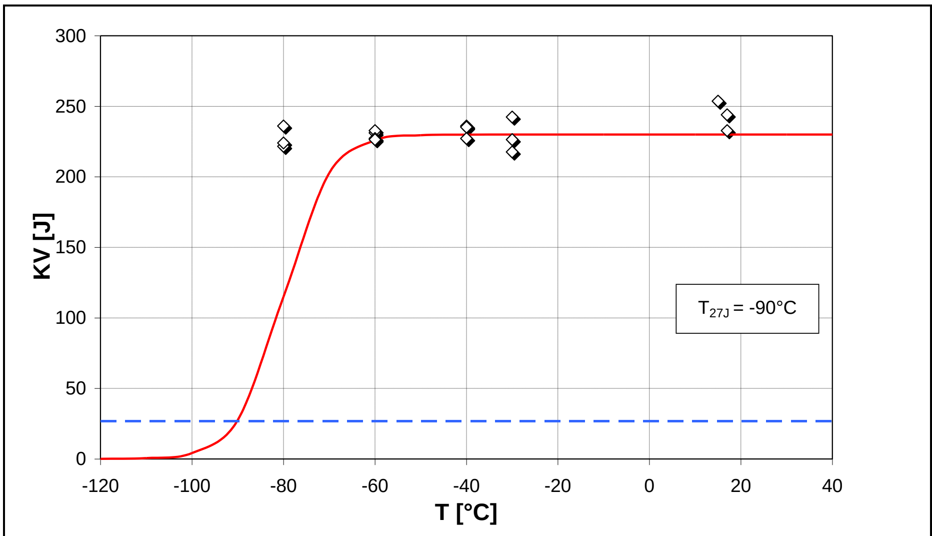
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
20	-24
22	-25
22	-26

RHS 100x100x8 – plane area



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
16	-50
18	-32

RHS 100x100x8 – bent area



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 100x100x8 – bent area aged

No.8 B0321 – RHS 150x150x8 (S460MLH acc. to EN 10219)

Delivered as grade S460MLH from European supplier B.

Thermo-mechanically rolled micro-alloyed fine grain steels.

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
150	150	8	19,8	12,6

Geometric dimensions of CVN-specimen

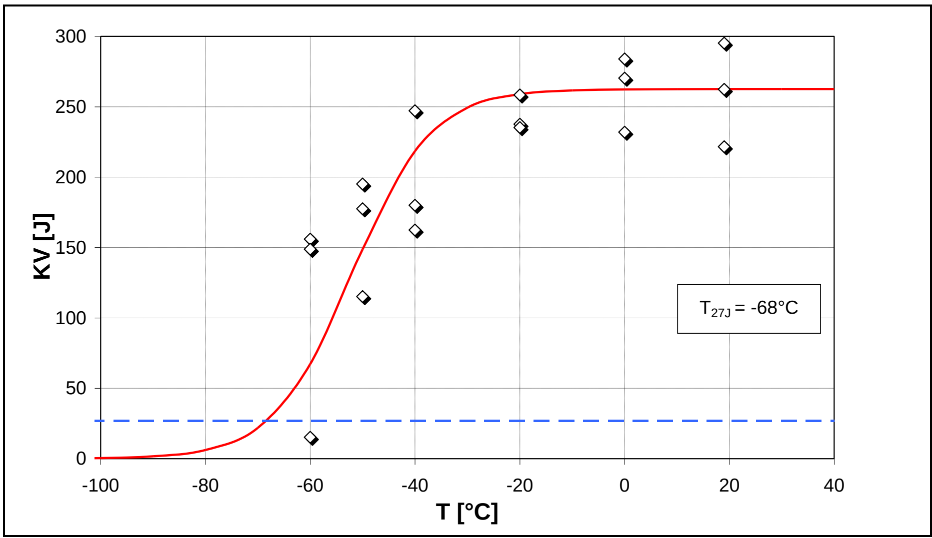
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	8	1,6	0,64	4,80

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,082	0,018	1,116	0,017	0,007	0,015		0,034	0,002	0,003

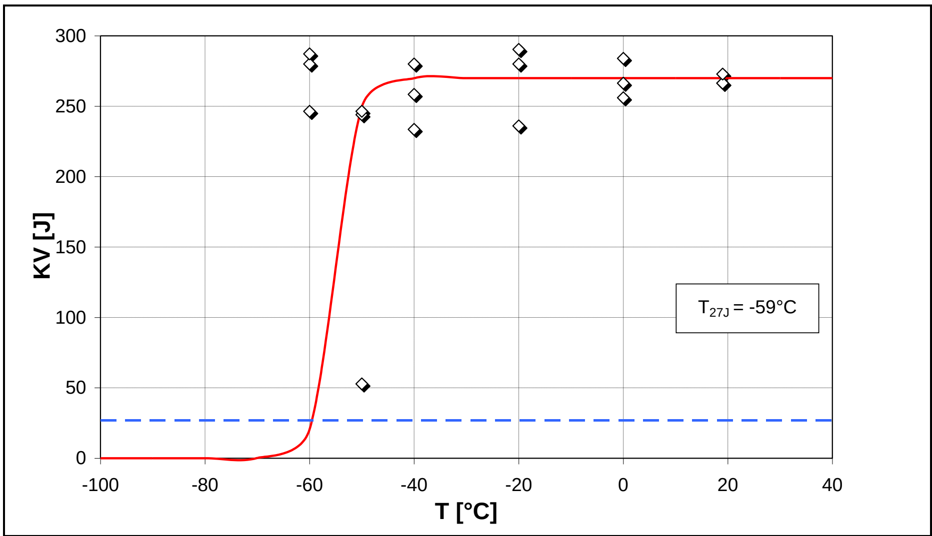
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,004	0,050	0,013	0,060						0,007		

Impact energies



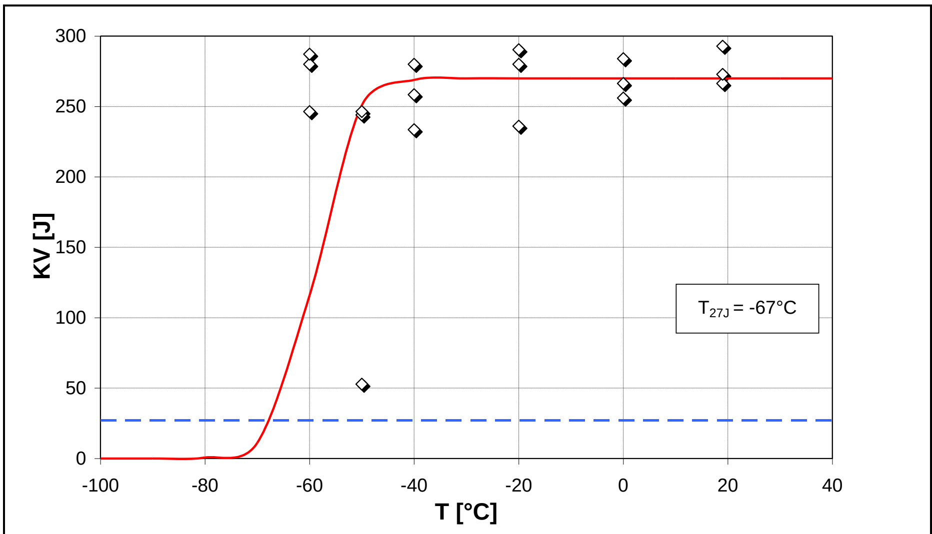
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 150x150x8 – plane area



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
53	-67

RHS 150x150x8 – bent area



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
53	-67

RHS 150x150x8 – bent area aged

Annex A.1.2 Results from CIDECT 1B-report [15]

Sampling:

(1) Notch position was parallel to the surface as given in the following figures taken from the CIDECT 1B report.

No.9 1B-1 - RHS 254x254x15,9 (Steel equivalent to A500C ASTM A500-01, class C)

Delivered as grade A500C from Canadian supplier.

Traditional C-Mn-steels with C 0,18 % … 0,21 %.

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
254	254	15,9	31,8	15,9

Geometric dimensions of CVN-specimen

dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	10	2	0,80	8,95

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,210	0,040	0,790	0,007	0,005	0,160		0,037	0,060	

Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,050	0,000										

Sampling according to Figure A1-3.

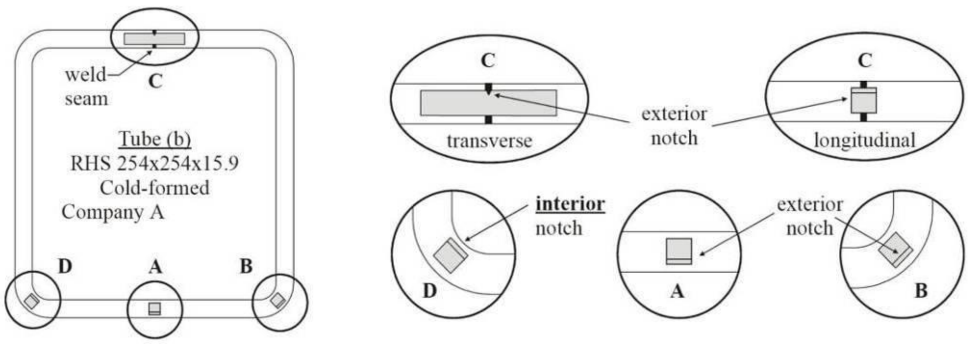
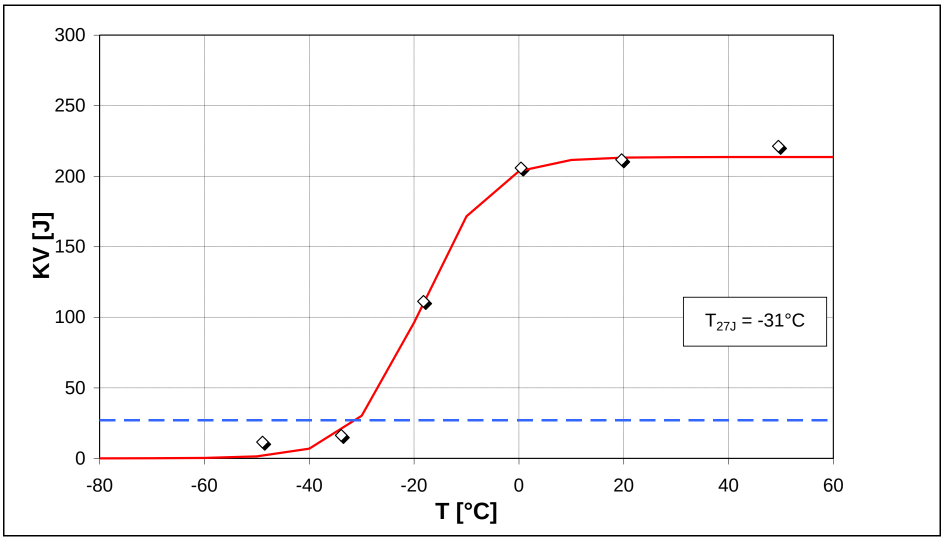


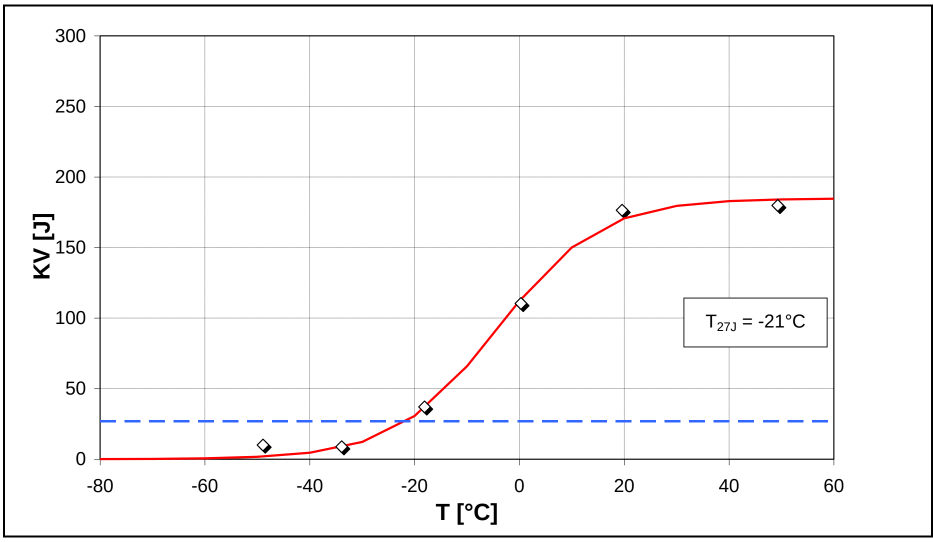
Figure A1-3: Position of Charpy-samples

Impact energies



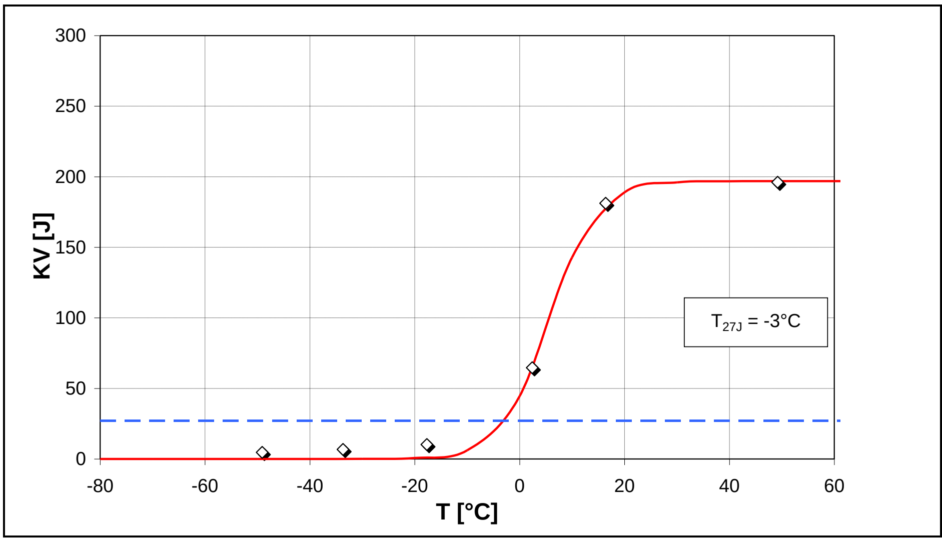
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
16	-24

RHS 254x254x15,9 – plane area, longitudinal direction



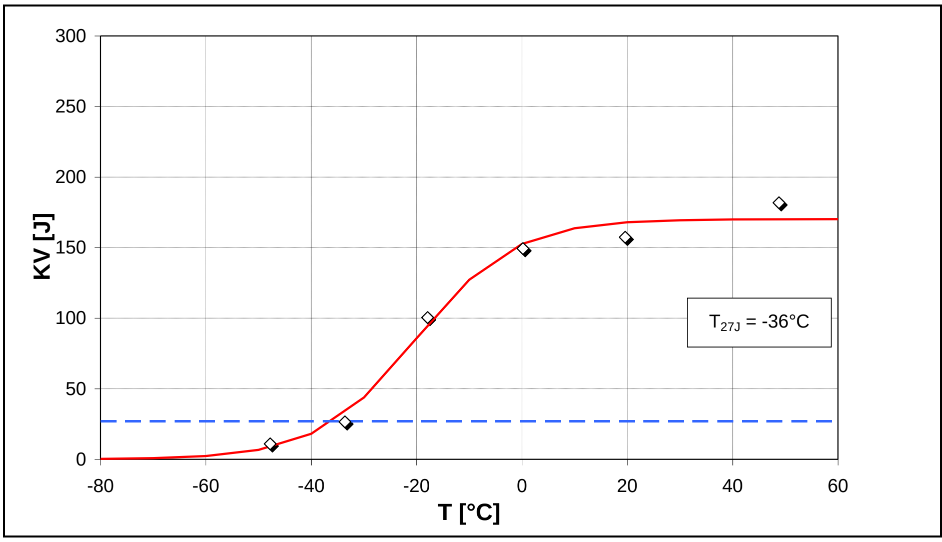
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
37	-26

RHS 254x254x15,9 – bent area, outer notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
65	-21

RHS 254x254x15,9 – bent area, inner notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
27	-33

RHS 254x254x15,9 – plane area, seam weld

No.10 1B-2 - RHS-102x102x12,7 (Steel equivalent to A500C ASTM A500-01, class C)

Delivered as grade A500C from Canadian supplier.

Traditional C-Mn-steels with C 0,18 % … 0,21 %.

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
102	102	12,7	24,4	12,7

Geometric dimensions of CVN-specimen

dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	10	2	0,80	7,35

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,180	0,050	0,810	0,011	0,006			0,041	0,020	

Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,063											

Sampling according to Figure A1-4.

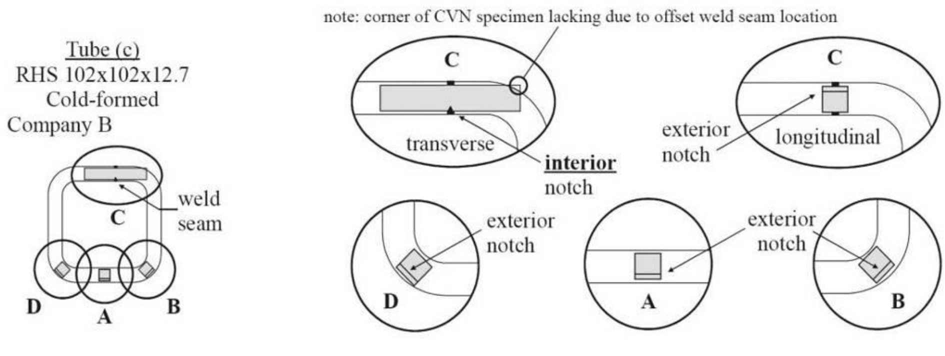
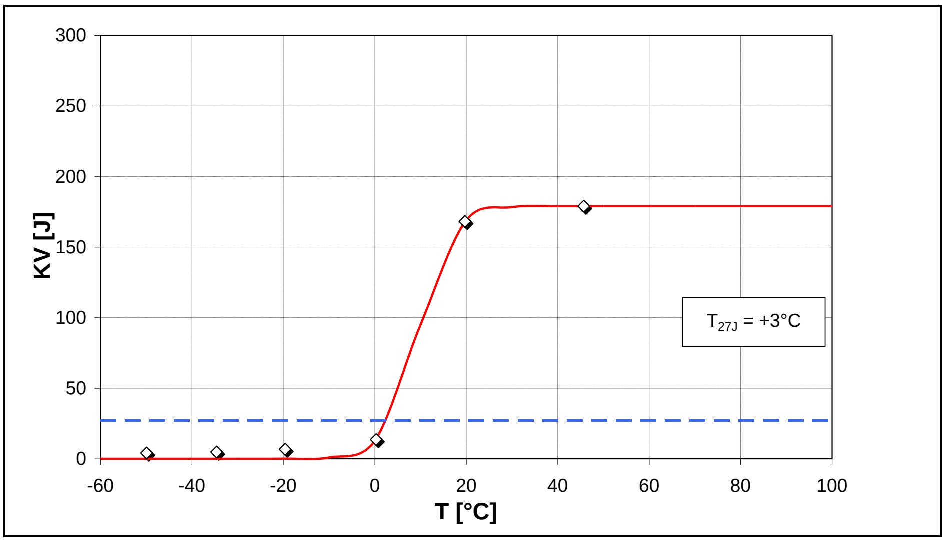


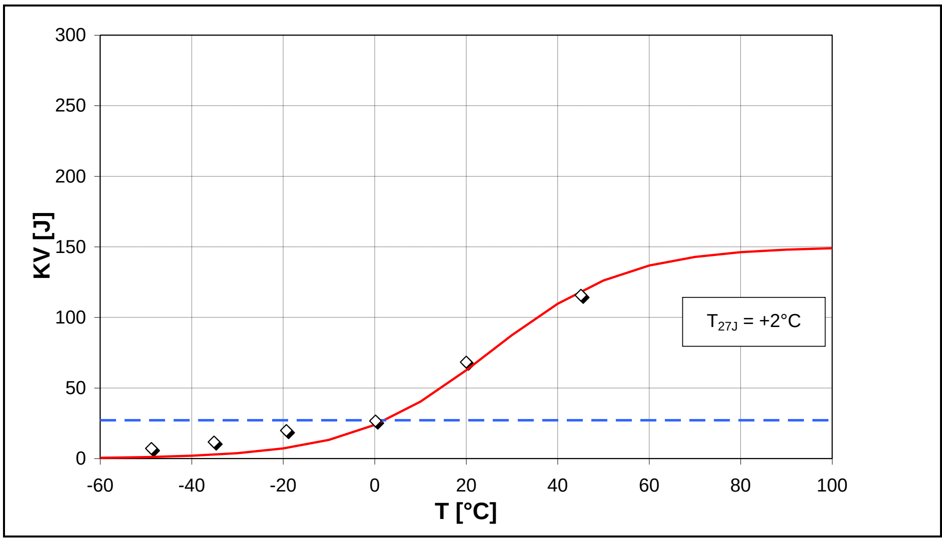
Figure A1-4: Position of Charpy-samples

Impact energies



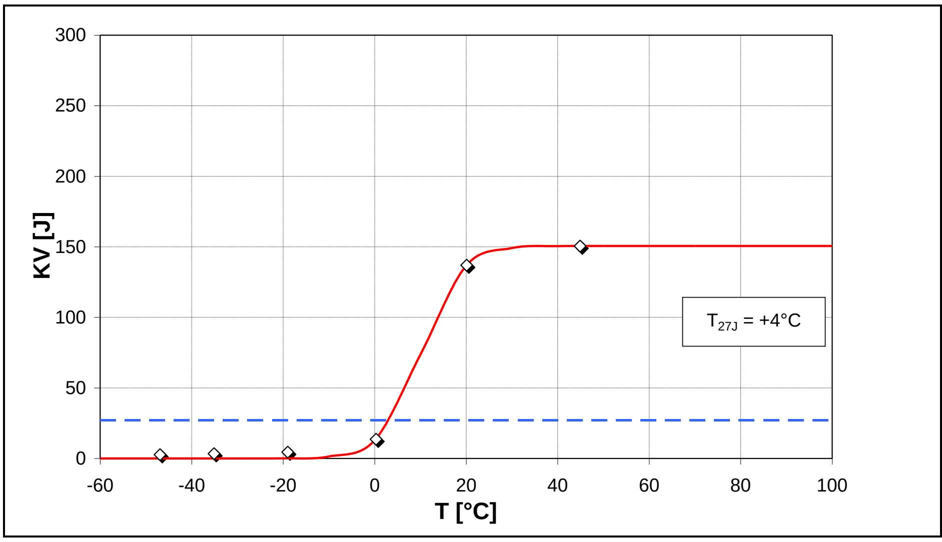
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 102x102x12,7 – plane area, longitudinal direction



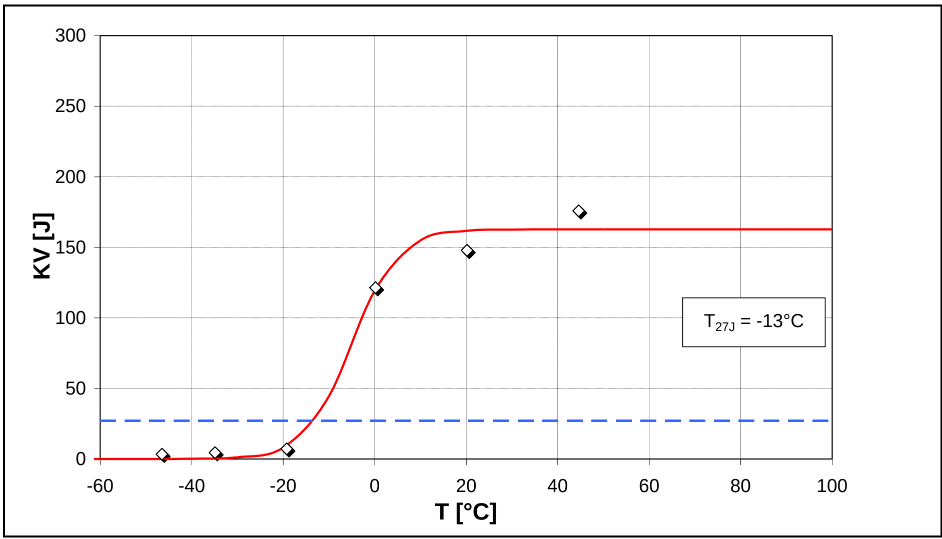
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
20	-13
27	+1

RHS 102x102x12,7 – plane area, transversal direction



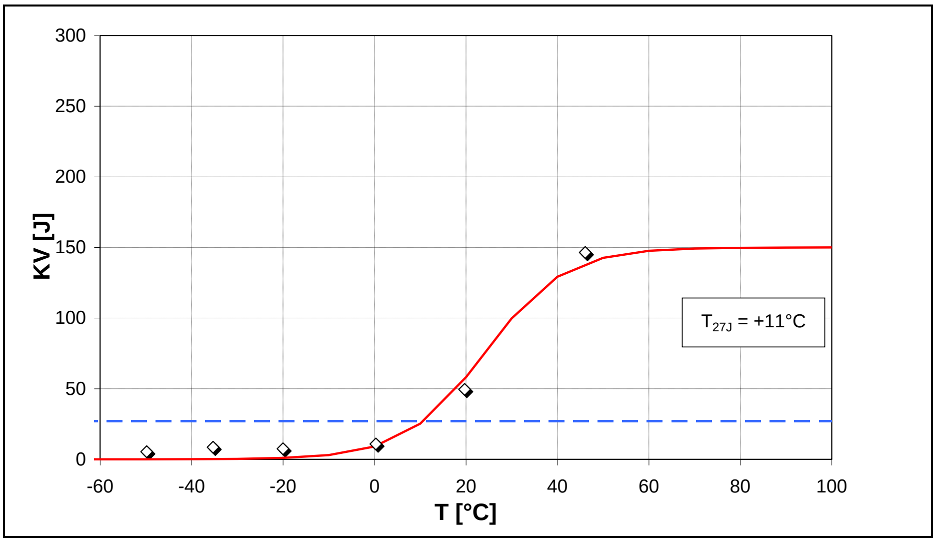
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 102x102x12,7 – (right) bent area, outer notch



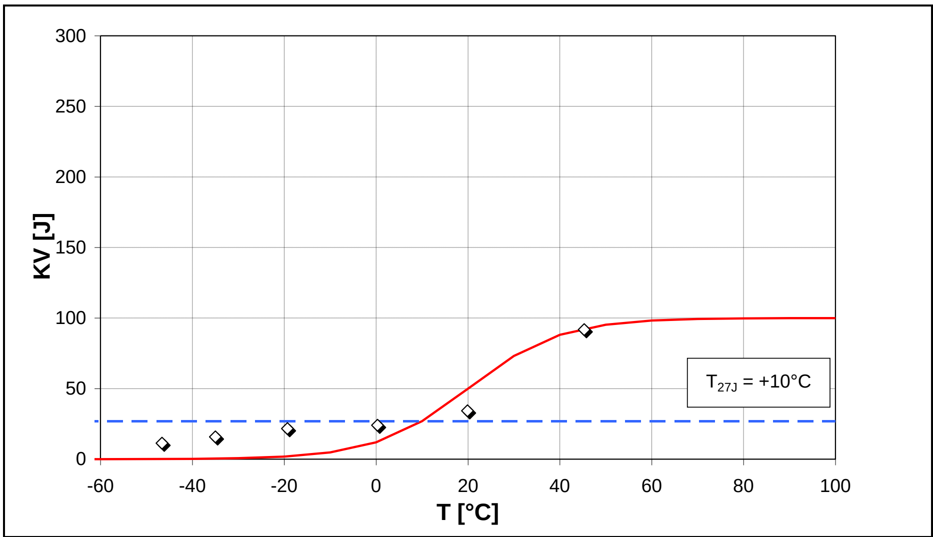
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 102x102x12,7 – (left) bent area, outer notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
50	4

RHS 102x102x12,7 – seam weld, longitudinal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
22	-15
24	+3
34	+14

RHS 102x102x12,7 – seam weld, transversal direction

No.11 1B-3 - RHS 250x250x12,5 (Steel S355J2H acc. to EN 10219)

Delivered as grade S355J2H, certified with Charpy-V-testing at -40 °C / 27 J from European supplier A.

Manufactured from micro-alloyed thermo-mechanically rolled fine grain steel.

Concerning Charpy-V-energy these products confirm with S355K2H and S355MH or S420MH.

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
250	250	12,5	37,5	25,0

Geometric dimensions of CVN-specimen

dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	10	2	0,80	7,25

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,070	0,210	1,430	0,012	0,005	0,018		0,039	0,027	0,004

Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,035	0,007	0,016	0,025					0,004			

Sampling according to Figure A1-5.

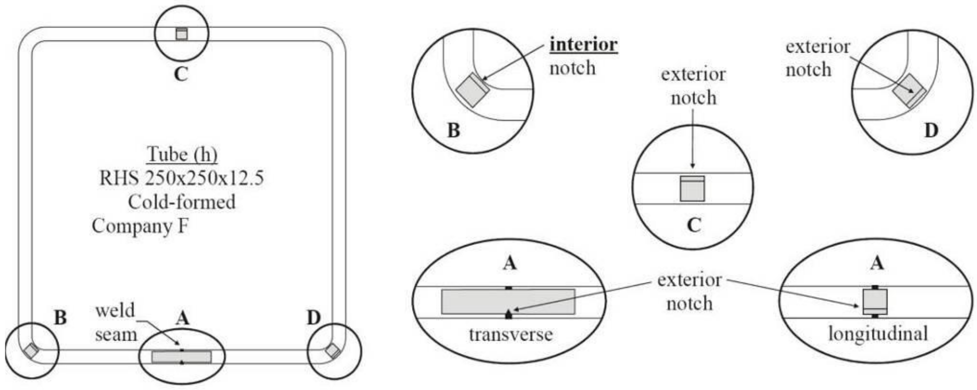
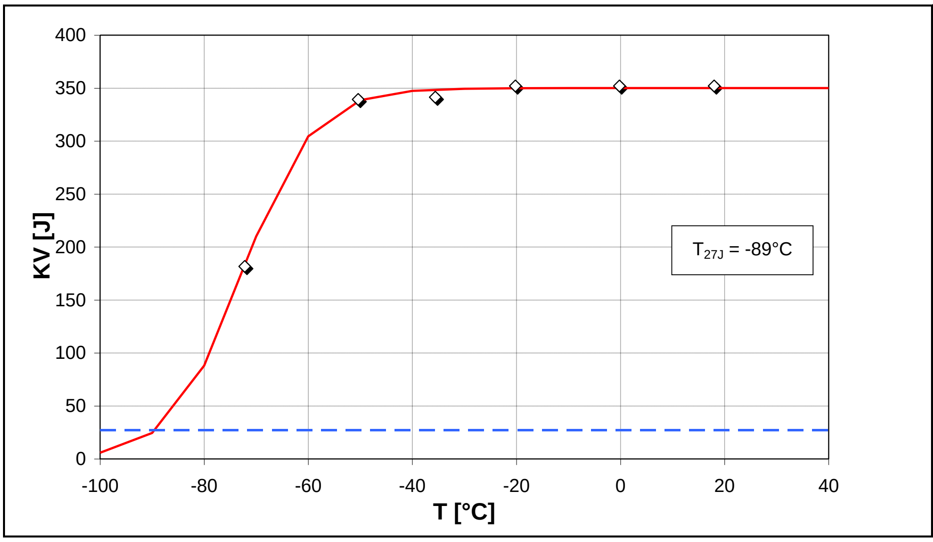


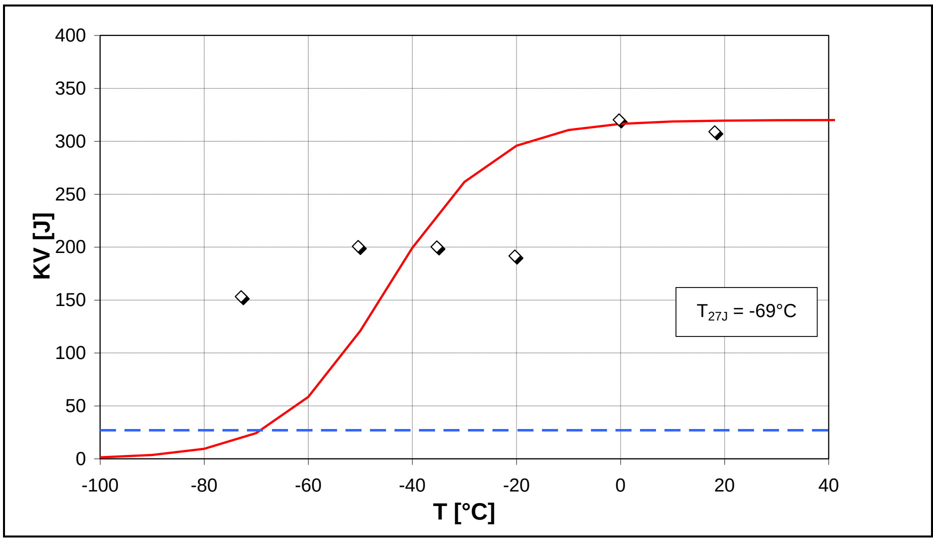
Figure A1-5: Position of Charpy-samples

Impact energies



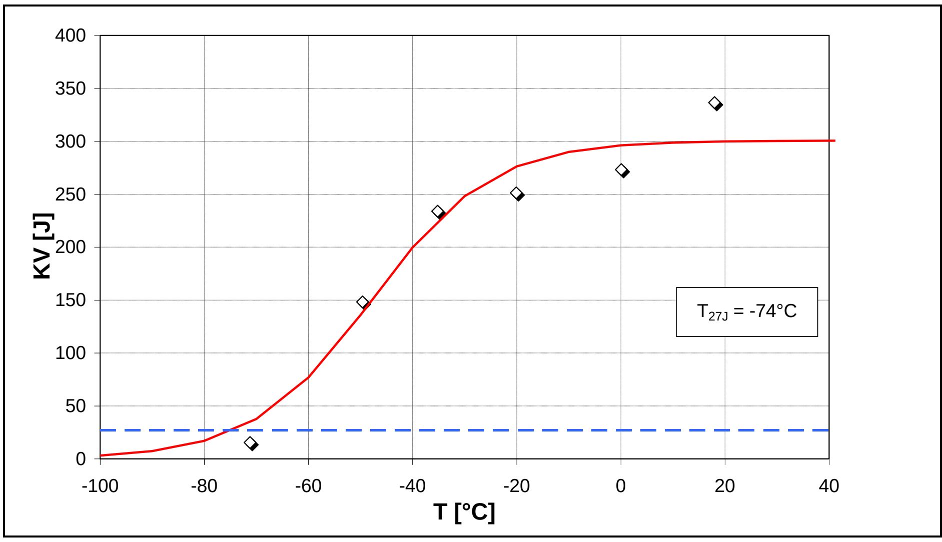
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 250x250x12,5 – plane area, longitudinal direction



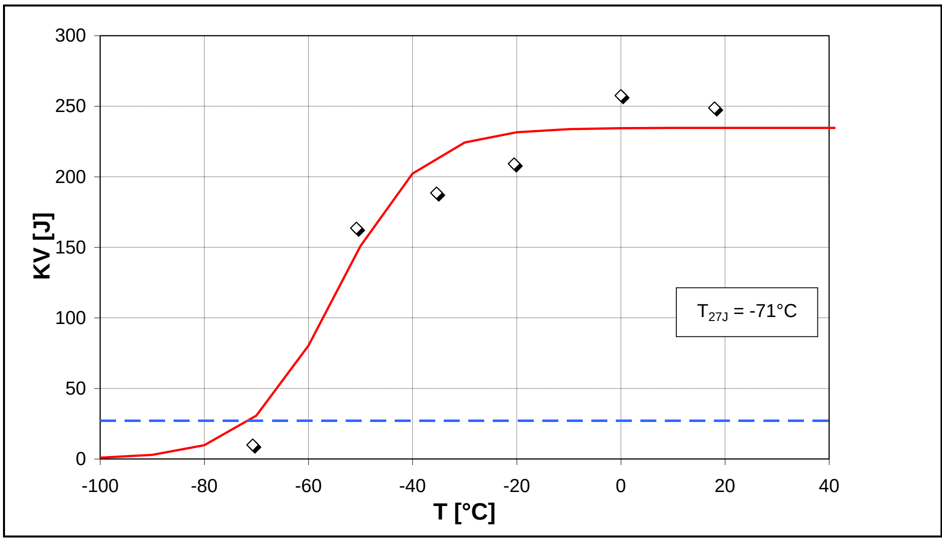
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 250x250x12,5 – plane area, transversal direction



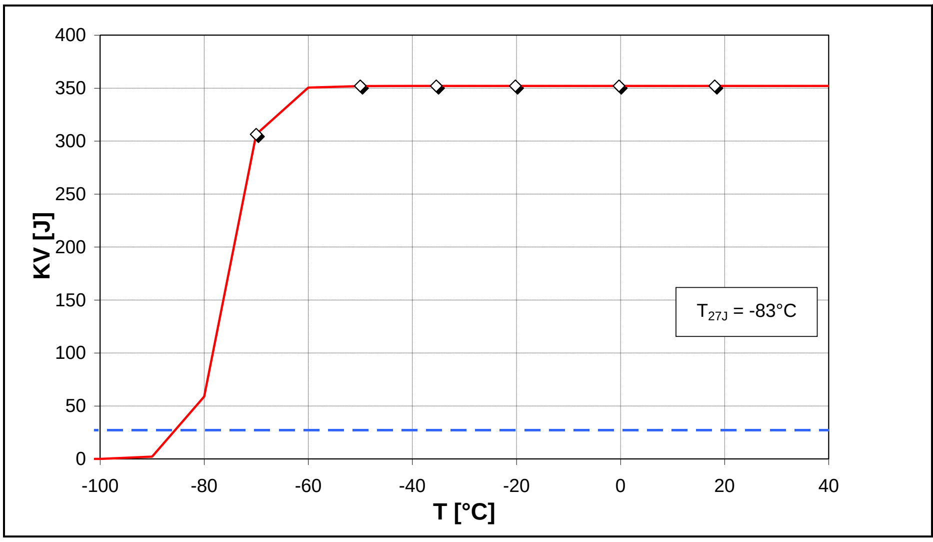
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 250x250x12,5 – bent area, outer notch



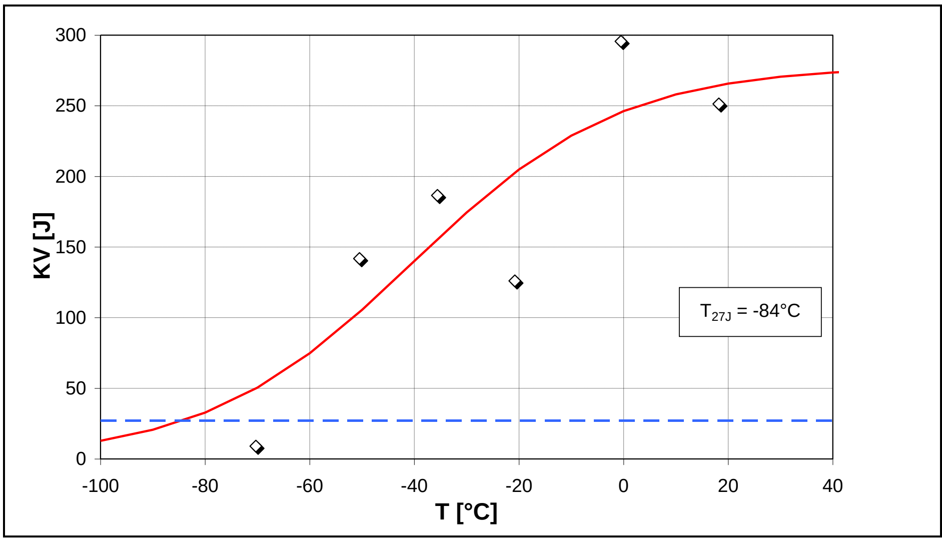
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 250x250x12,5 – bent area, inner notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 250x250x12,5 – seam weld, longitudinal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 250x250x12,5 – seam weld, transversal direction

No.12 1B-4 - RHS 255x255x8,4 (Steel equivalent to A53B ASTM A53/A53M-01,cold-shaped), final tube

The material has been produced with a specific process not considered in EN 10219.

The test records are included in this report, however, the results of the evaluation have not been considered in the conclusions.

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
255	255	8,4	16,0	7,9

Geometric dimensions of CVN-specimen

dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	5	1	0,40	4,70

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,100	0,210	0,960	0,013	0,004	0,000		0,024	0,020	0,020

Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,010	0,000										

Sampling according to Figure A1-6.

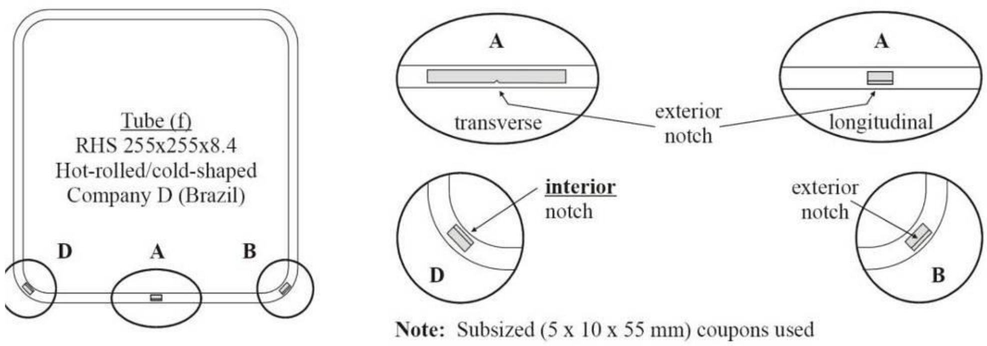
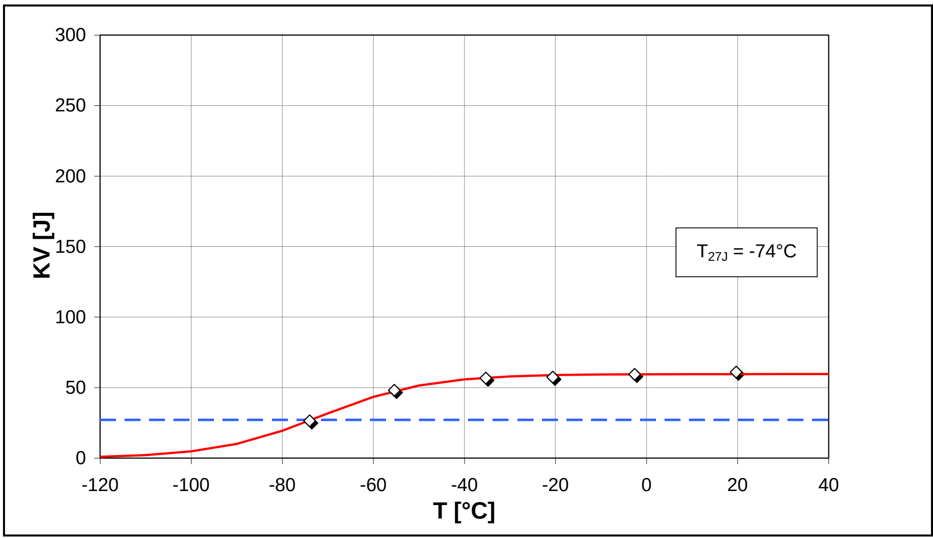


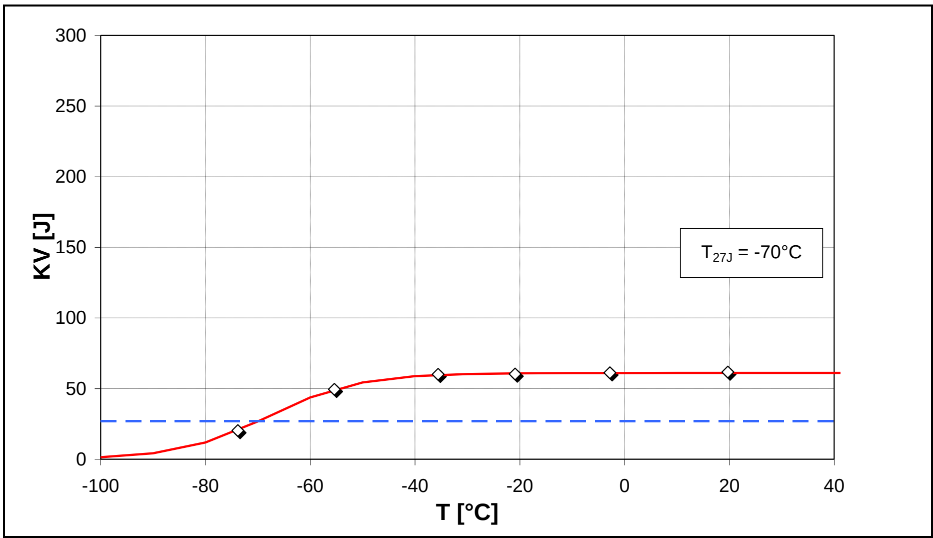
Figure A1-6: Position of Charpy-samples

Impact energies



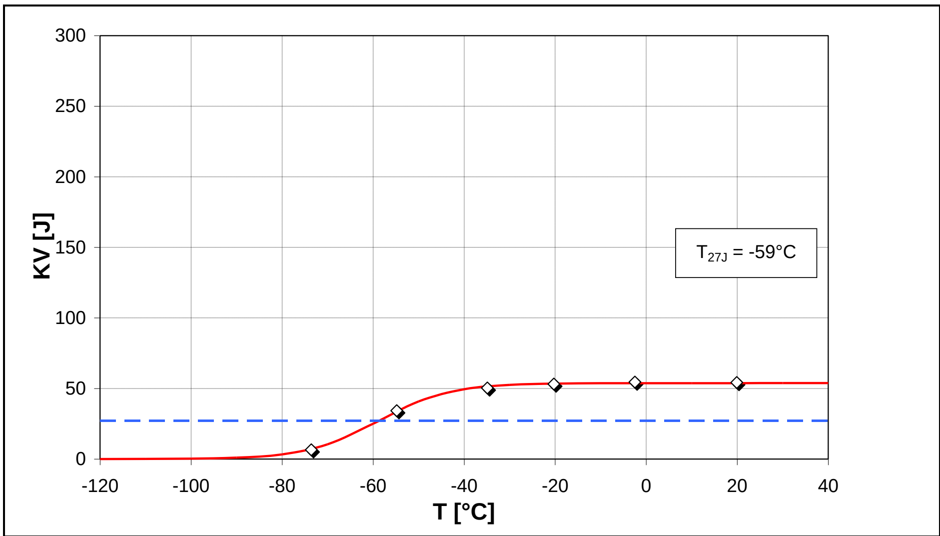
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
26	-73
48	-70
57	-55
57	-40
59	-23
61	-2

RHS 255x255x8,4 – plane area, longitudinal direction



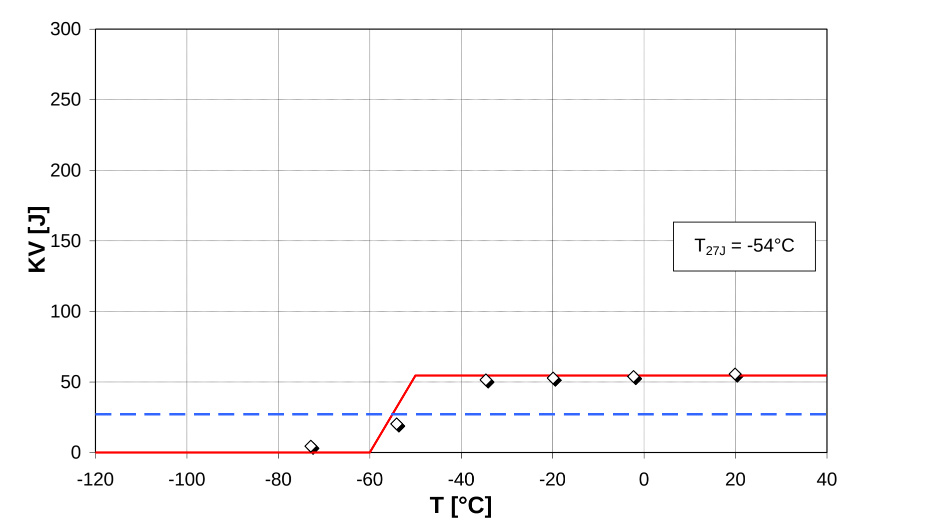
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
20	-68
50	-71
60	-57
60	-42
61	-25
62	-2

RHS 255x255x8,4 – plane area, transversal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
34	-60
50	-51
53	-38
55	-21
54	2

RHS 255x255x8,4 – bent area, outer notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
20	-48
52	-51
53	-37
54	-20
56	1

RHS 255x255x8,4 – bent area, inner notch

Annex A.1.3 Results from Dagg [13]

(1) RHS-hollow sections cold-formed to AS1163.

(2) Through-thickness notch orientation was applied, so that the notch was positioned in the core area.

(3) Subsized specimens with 55 x 10 x 5 mm were machined from the sections according to Figure A1-7.

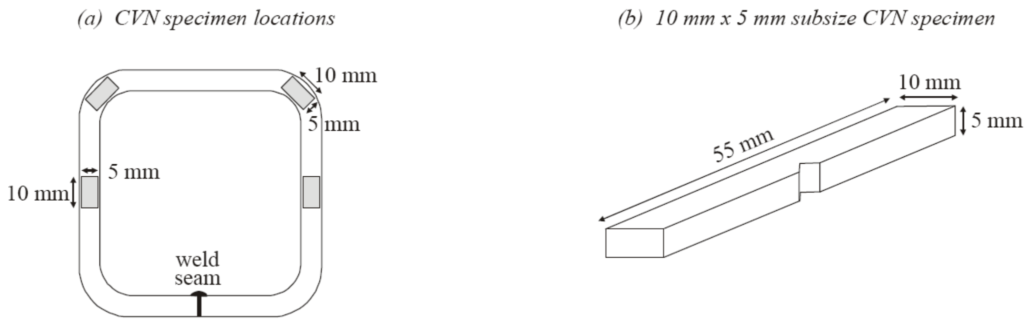


Figure A1-7: Position of Charpy-samples

(4) CVN test specimens were artificially aged at 170 °C for 30 minutes.

(5) The records are included in this report, however, the results of the test evaluation are not considered in the conclusions.

No.13 Dagg-1 - RHS 203 x 203 x 9,5 – Steel grade unknown

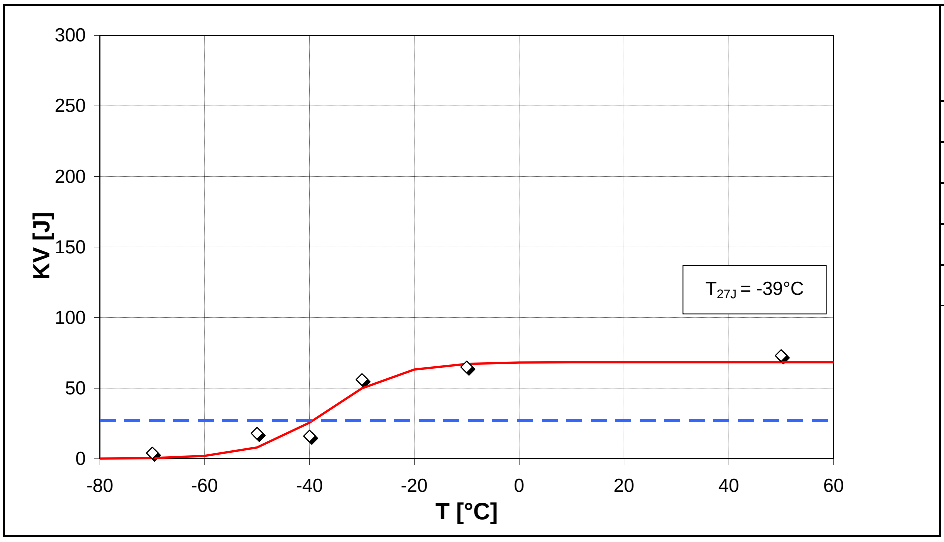
Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
203	203	9,5	19,1	9,5

Geometric dimensions of CVN-specimen

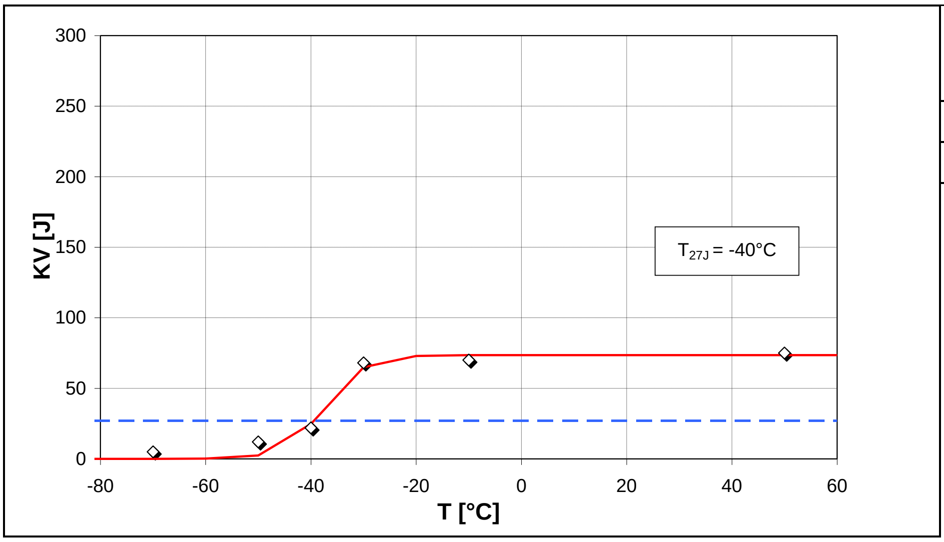
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	5	10	2	0,40	4,75

Impact energies



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
18	-42
16	-30
56	-49
65	-34

RHS 203x203x9,5 – plane area, longitudinal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
22	-36

RHS 203x203x9,5 – bent area

No.14 Dagg-2 - RHS 76 x 76 x 6,3 – Steel grade unknown

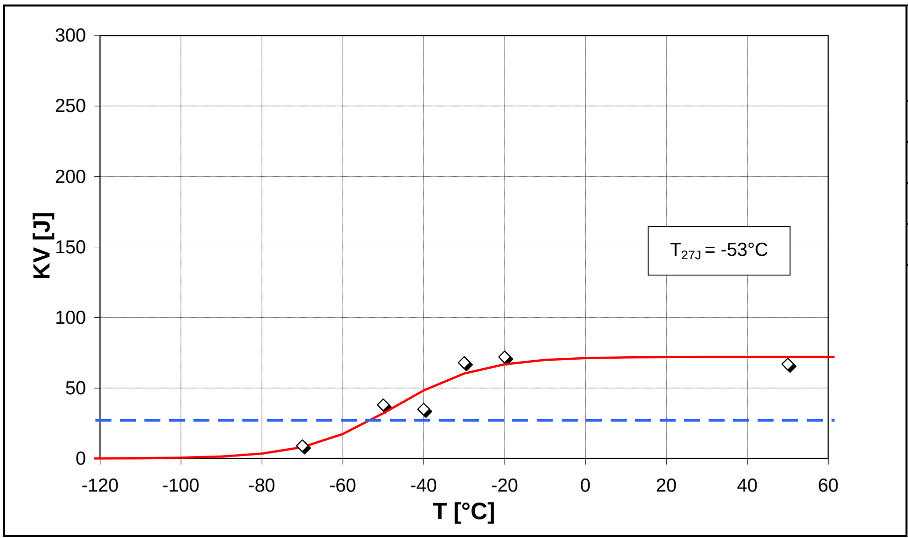
Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
76	76	6,3	12,7	6,4

Geometric dimensions of CVN-specimen

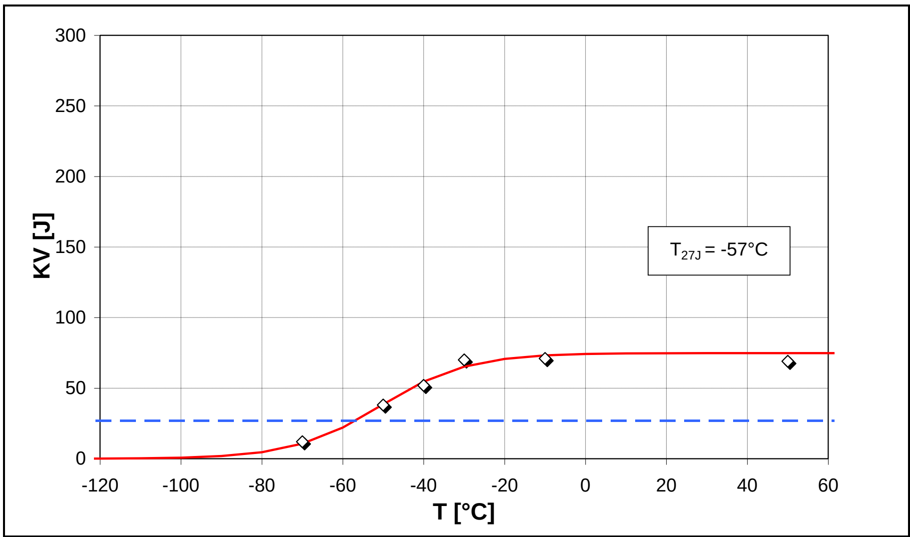
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	5	10	2	0,40	3,15

Impact energies



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
38	-58
35	-46
67	25

RHS 76x76x6,3 – plane area, longitudinal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
38	-58
52	-57

RHS 76x76x6,3 – bent area

Annex A.1.4 Results from RUUKKI – random data taken from corner region [11]

Sampling:

(1) The position of the sampling layers is given in Figure A1-8. The width of the specimen was either 10 mm or for tubes with t < 10 mm equal to the wall thickness of the tube. Notch position for the flat face was perpendicular to the surface in through-thickness direction.

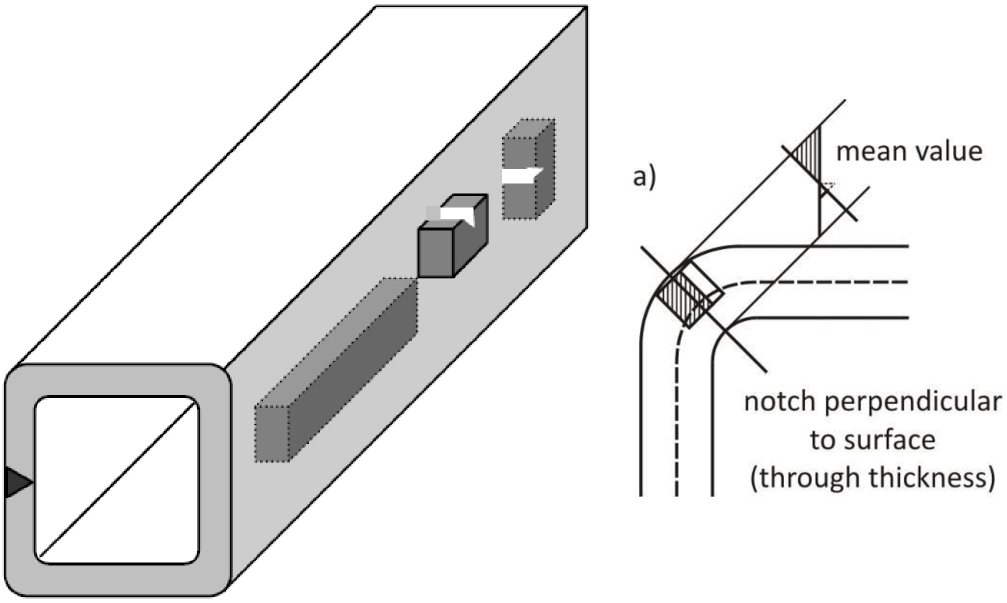


Figure A1-8: Position of Charpy-samples, flat face

(2) In order to verify whether there is a significant difference due to the notch position, the samples in the corner regions have been orientated parallel to the surface, see Figure A1-9.

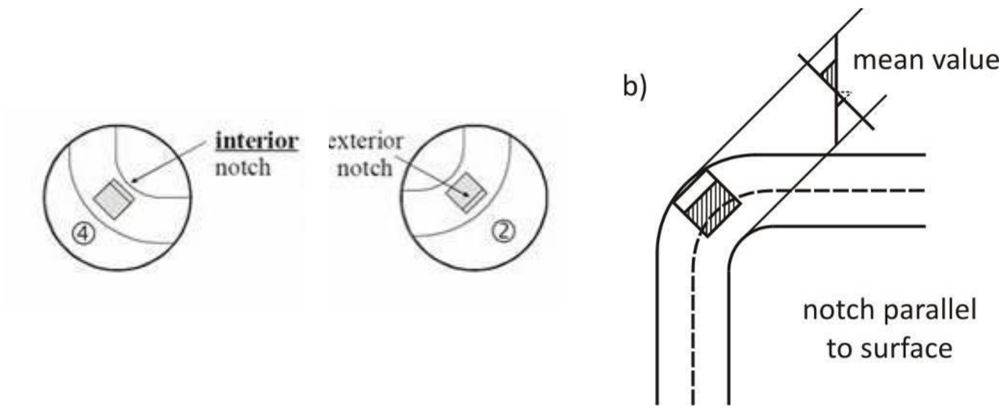


Figure A1-9: Position of Charpy-samples, bent area

No.19 Ruukki-1 - Different RHS profiles (S355J2H acc. to EN 10219)

Delivered as grade S355J2H, certified with Charpy-V-testing at -40 °C / 27 J from European supplier A.

Manufactured from micro-alloyed thermo-mechanically rolled fine grain steel.

Concerning Charpy-V-energy these products confirm with S355K2H and S355MH or S420MH.

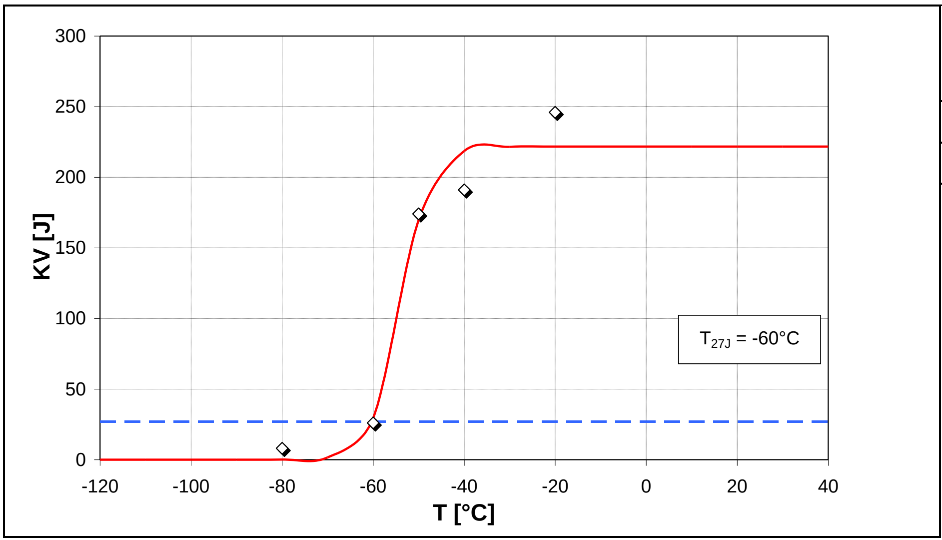
Geometric dimensions of hollow section

	b	**h**	**t**	**r_a**	**r_i**
	[mm]	[mm]	[mm]	[mm]	[mm]
220x120x12,5	220	120	12,5	25,0	12,5
150x150x12,5	150	150	12,5	37,5	25,0
250x250x10	250	250	10	30,0	20,0

Geometric dimensions of CVN-specimen

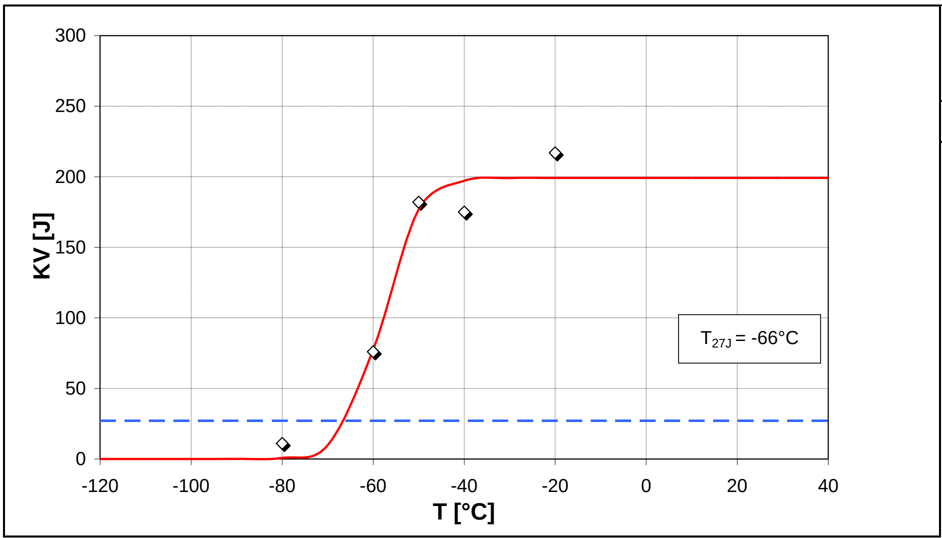
	dimensions			**notch depth**	**notch area**	**position of CVN core area**
	l	**w**	**h**	**c**	**A**	**z**
	[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
220x120x12,5	55	10	10	2	0,80	7,25
150x150x12,5	55	10	10	2	0,80	7,25
250x250x10	55	7,5	10	2	0,60	6,00

Impact energies



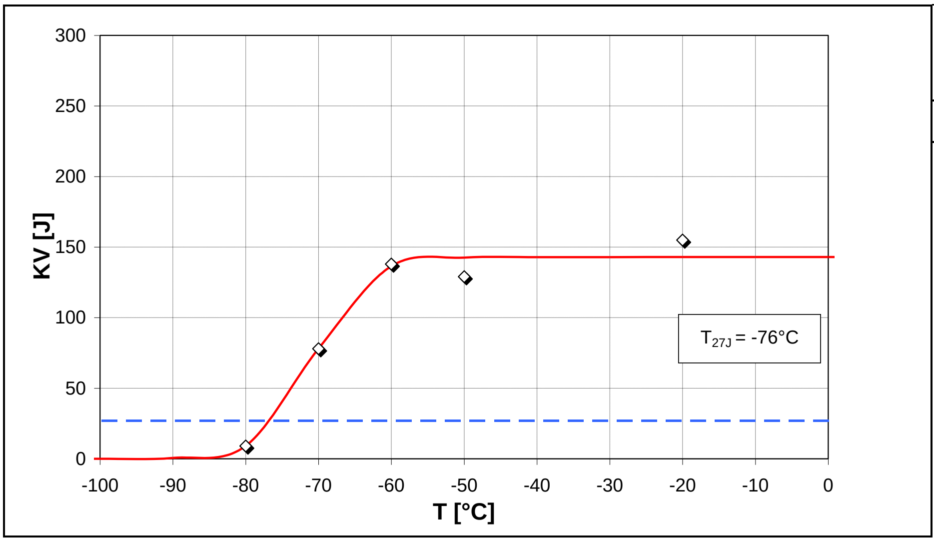
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
26	-59

RHS 220x120x12,5 – bent area, notch out



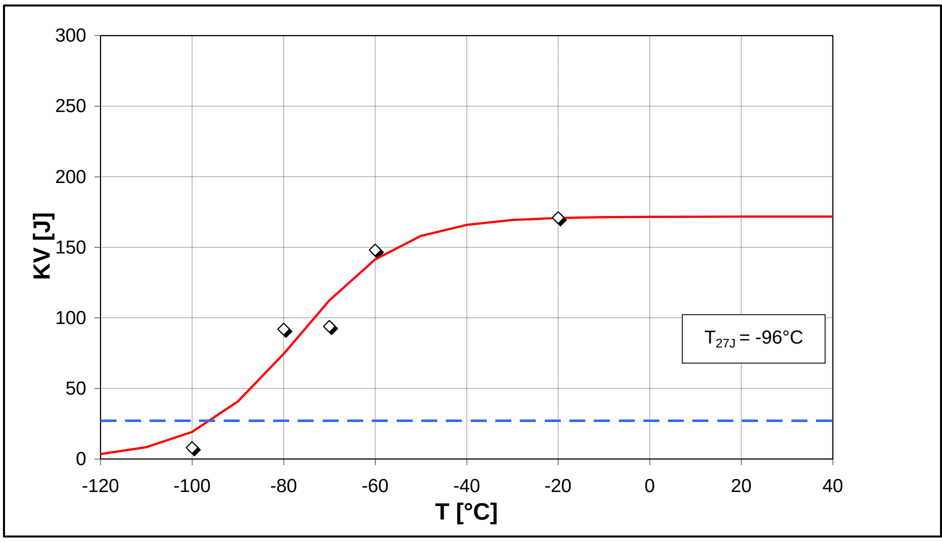
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 150x150x12,5 – bent area, notch out



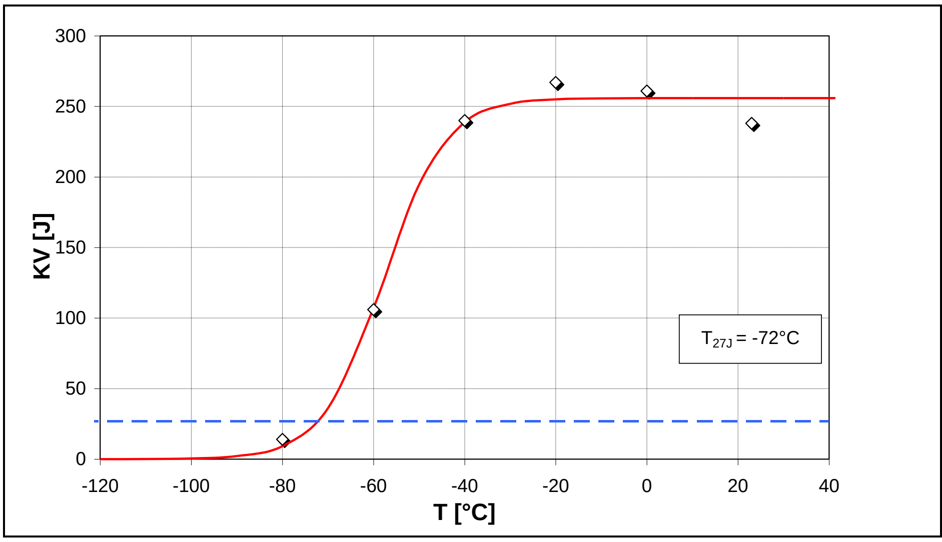
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 250x250x10 – bent area, notch out (1)



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 250x250x10 – bent area, notch out (2)



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 150x150x12,5 – bent area, notch in

No.20 Ruukki-2 - RHS 300x100x8 (S355J2H acc. to EN 10219)

Delivered as grade S355J2H, certified with Charpy-V-testing at -40 °C / 27 J from European supplier A.

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
300	100	8	20,0	12,0

Geometric dimensions of CVN-specimen

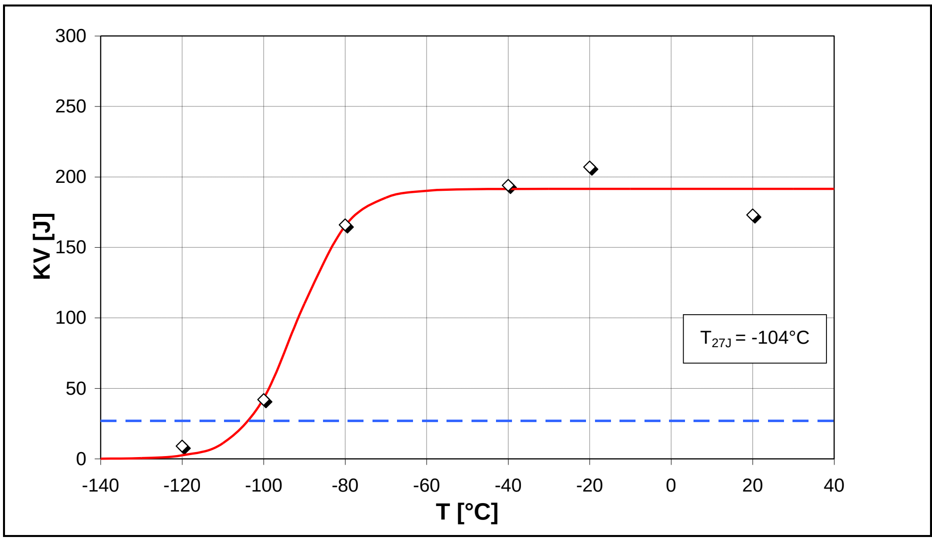
	dimensions			notch depth	notch area	position of CVN core area
	l	w	h	c	A	z
	[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
flat face	55	7,8	10	2	0,62	4,00
corners	55	10	7	1,4	0,56	7,25

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,063	0,192	1,420	0,010	0,0033			0,040		

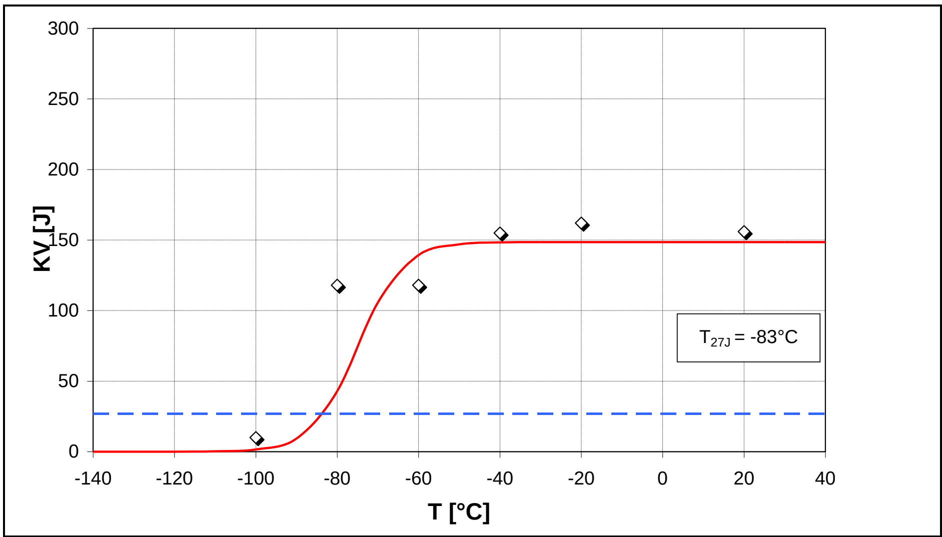
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
								0,0047			

Impact energies



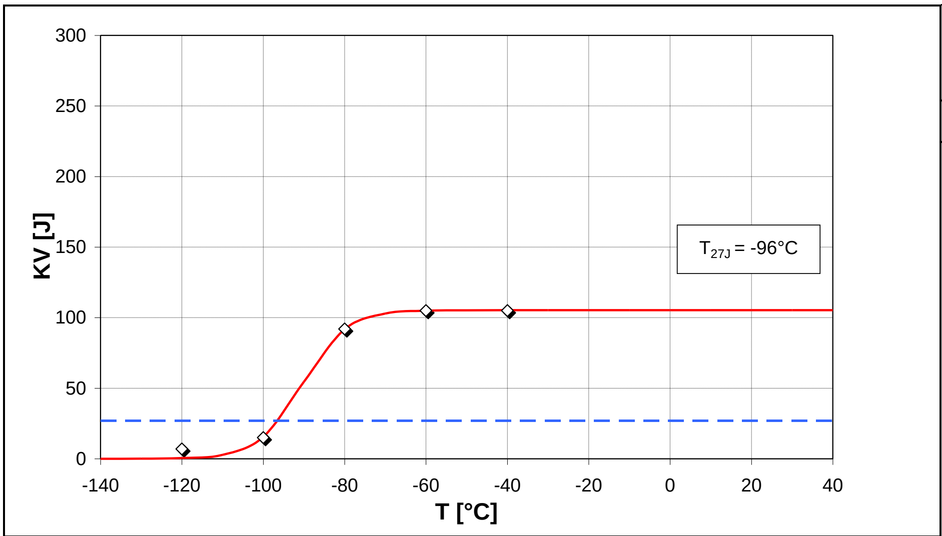
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
42	-111

RHS 300x100x8 – plane area, longitudinal direction



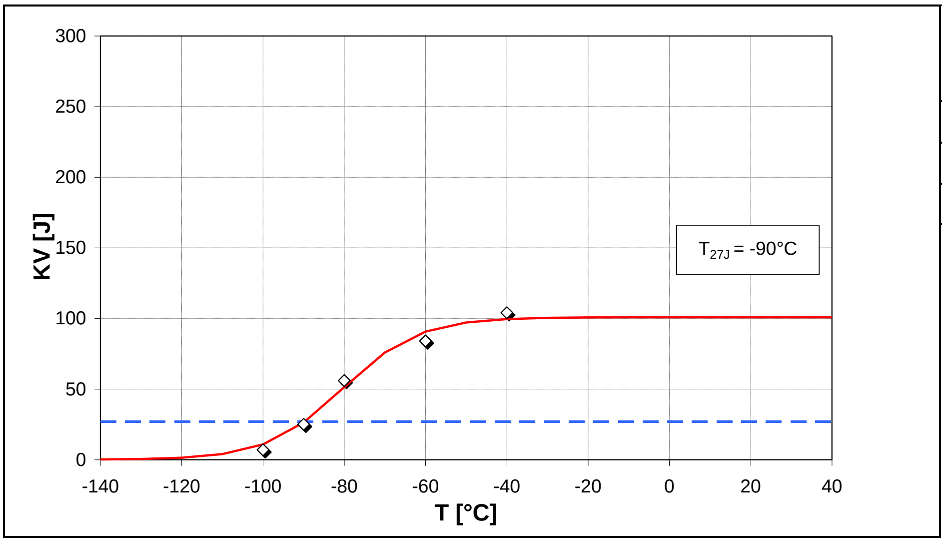
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 300x100x8 – plane area, transversal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 300x100x8 – bent area, notch in



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
56	-99
25	-88

RHS 300x100x8 – bent area, notch out

No.21 Ruukki-3 - RHS 250x250x12,5 (S355J2H acc. to EN 10219)

Delivered as grade S355J2H, certified with Charpy-V-testing at -40 °C / 27 J from European supplier A.

Manufactured from micro-alloyed thermo-mechanically rolled fine grain steel.

Concerning Charpy-V-energy these products confirm with S355K2H and S355MH or S420MH.

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
250	250	12,5	37,5	25,0

Geometric dimensions of CVN-specimen

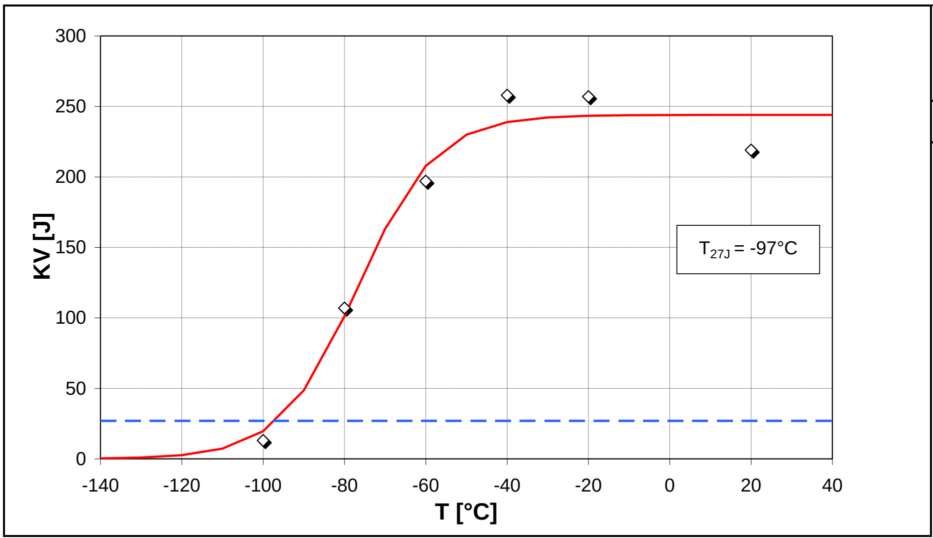
	dimensions			notch depth	notch area	position of CVN core area
	l	w	h	c	A	z
	[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
flat face	55	10	10	2	0,80	6,25
corners	55	10	10	2	0,80	7,25

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,059	0,189	1,040	0,008	0,0019			0,043		

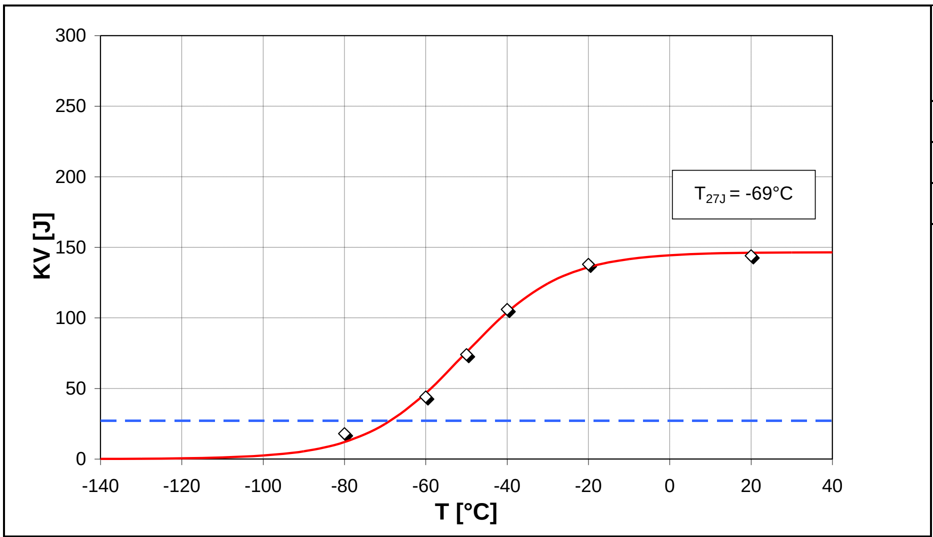
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
								0,0054			

Impact energies



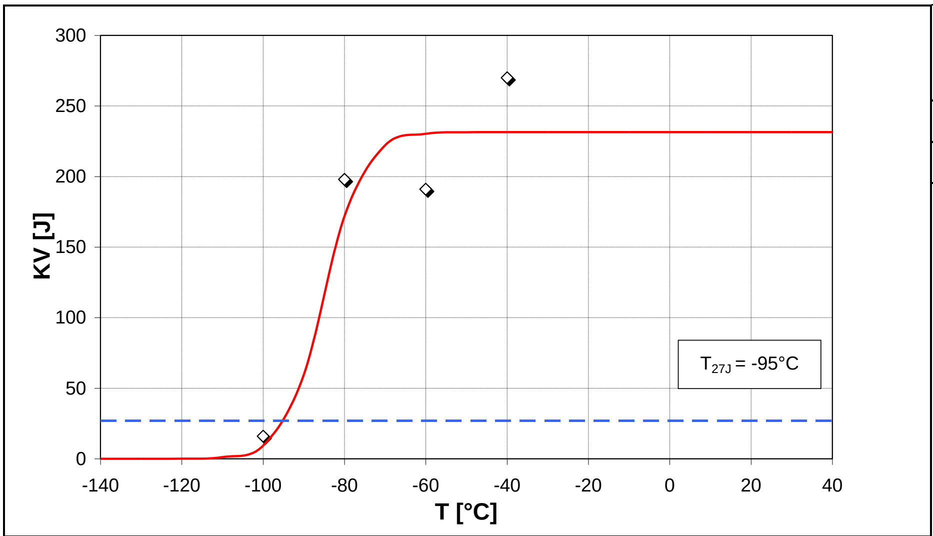
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 250x250x12,5 – plane area, longitudinal direction



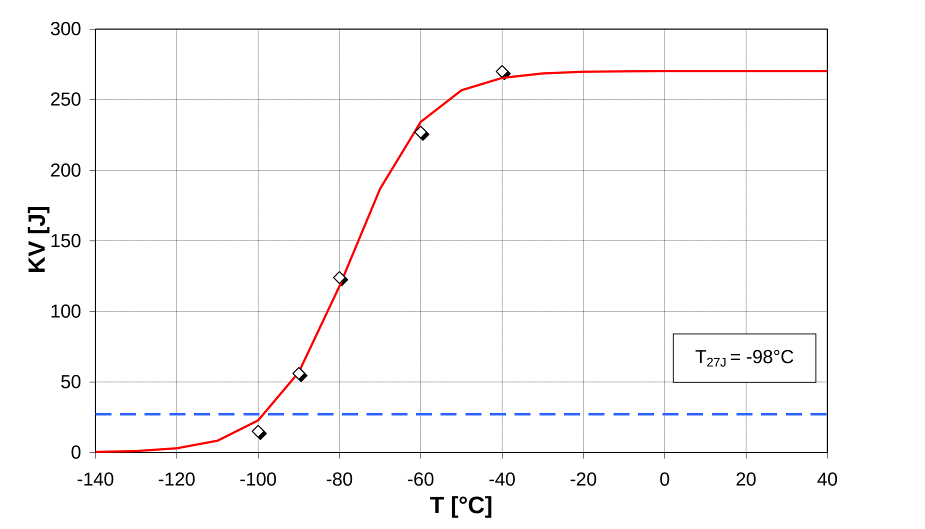
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
44	-72
18	-72

RHS 250x250x12,5 – plane area, transversal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
16	-90

RHS 250x250x12,5 – bent area, notch in



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
56	-109

RHS 250x250x12,5 – bent area, notch out

No.22 Ruukki-4 - RHS 200x200x12,5 (S355J2H acc. to EN 10219)

Delivered as grade S355J2H, certified with Charpy-V-testing at -40 °C / 27 J from European supplier A.

Manufactured from micro-alloyed thermo-mechanically rolled fine grain steel.

Concerning Charpy-V-energy these products confirm with S355K2H and S355MH or S420MH.

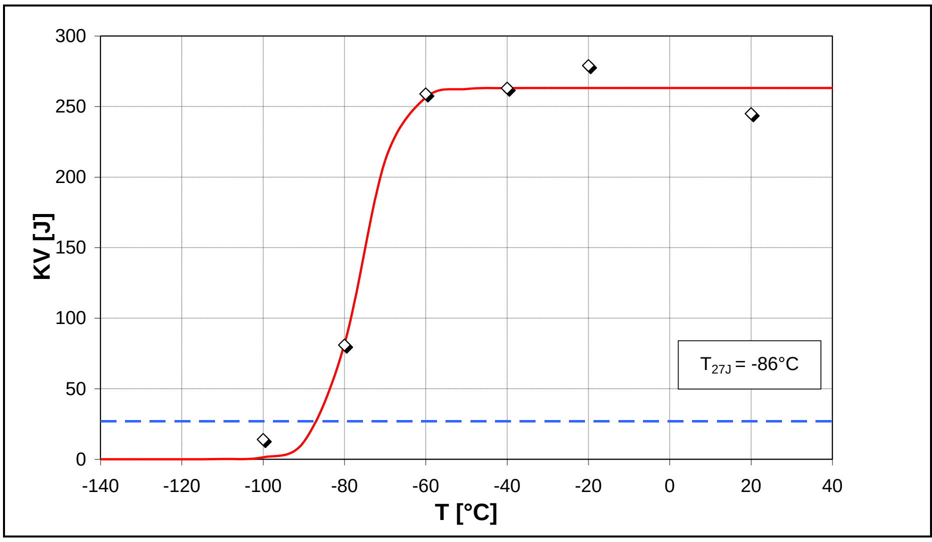
Geometric dimensions of hollow section

b	**h**	**t**	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
200	200	12,5	37,5	25,0

Geometric dimensions of CVN-specimen

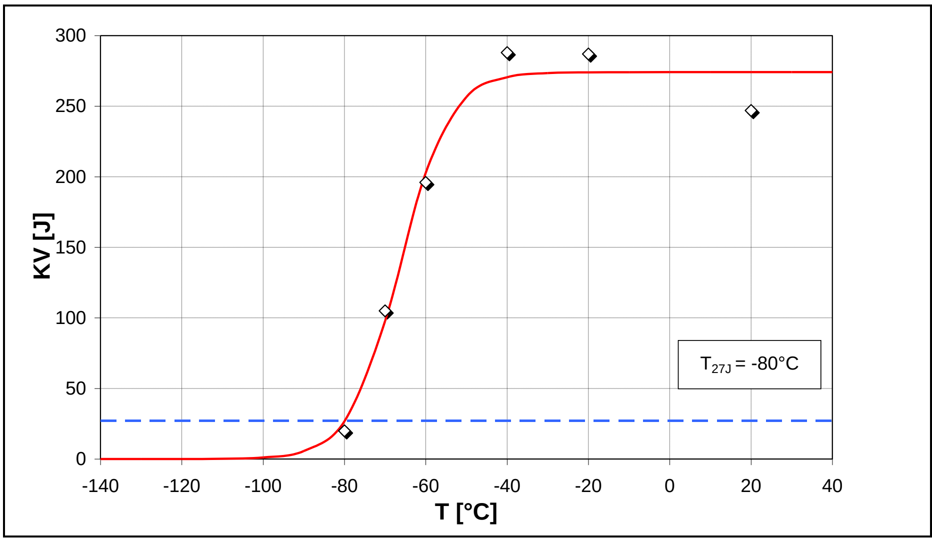
	dimensions			**notch depth**	**notch area**	**position of CVN core area**
	l	**w**	**h**	**c**	**A**	**z**
	[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
flat face	55	10	10	2	0,80	6,25
corners	55	10	10	2	0,80	7,25

Impact energies



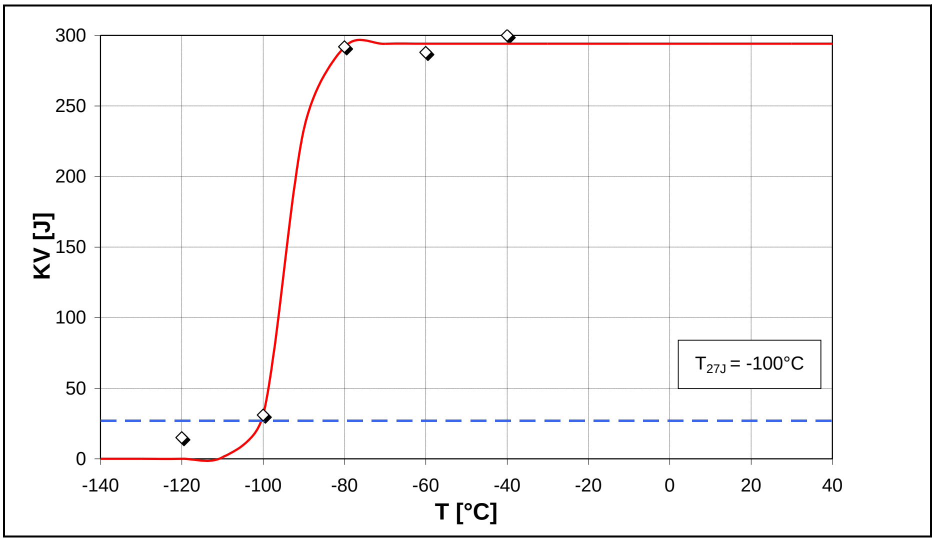
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 200x200x12,5 – plane area, longitudinal direction



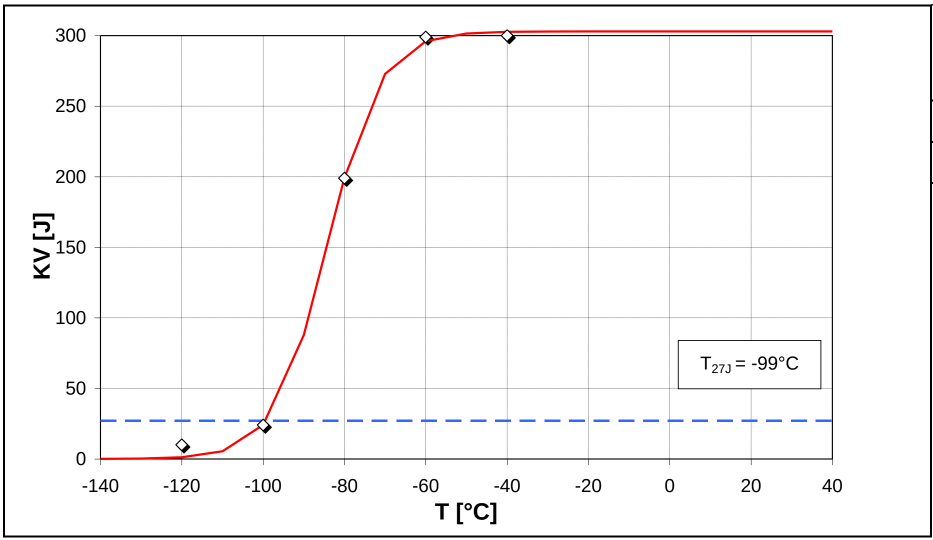
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
20	-74

RHS 200x200x12,5 – plane area, transversal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
31	-103

RHS 200x200x12,5 – bent area, notch in



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
24	-97

RHS 200x200x12,5 – bent area, notch out

Annex A.1.5 Results from Soininen –data taken from flat and corner regions (longitudinal and transversal data) + aged [12]

Sampling:

(1) The position of the sampling layers is given in Figure A1-10. Through-thickness notch orientation was applied, so that the notch position was perpendicular to the surface.

(2) The width of the specimen was either 10 mm or for tubes with t < 10 mm equal to the wall thickness of the tube.

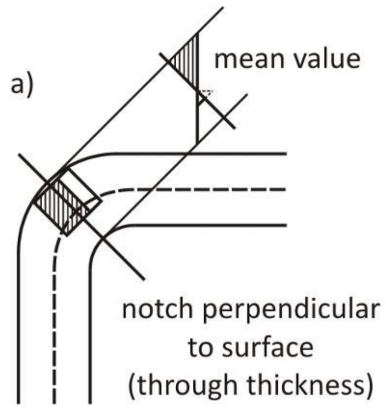


Figure A1-10: Position of Charpy-samples

No.23 Soininen-1 - RHS 100x100x10 (S355J2H acc. to EN 10219)

Delivered as grade S355J2H from European supplier A.

In the beginning of 1990's manufactured according to the then state of the art.

C-Mn-steels with some degree of micro-alloying.

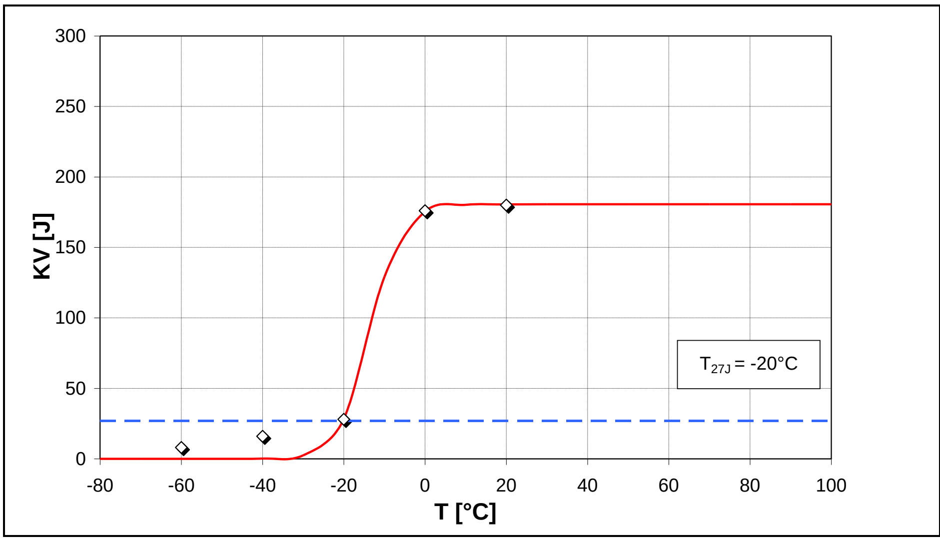
Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
100	100	10	30,0	20,0

Geometric dimensions of CVN-specimen

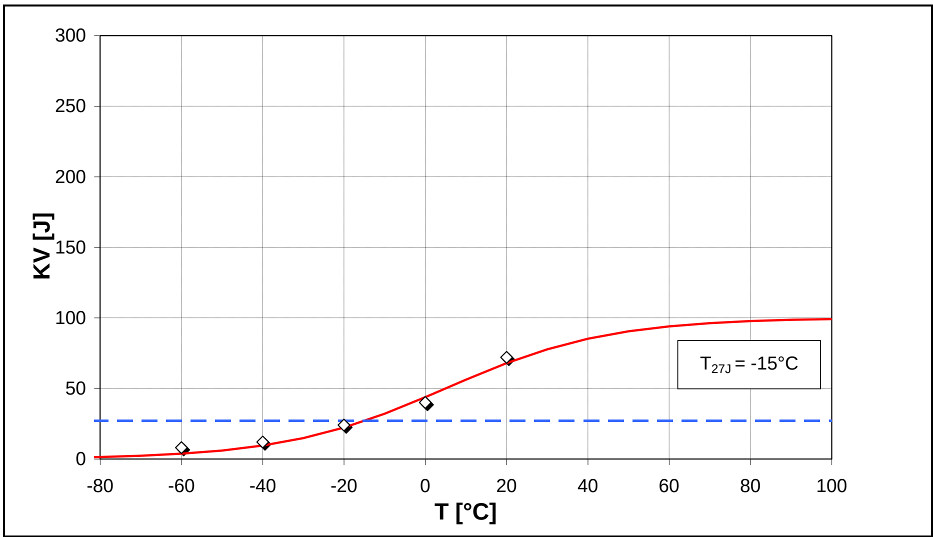
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	10	2	0,80	5,00

Impact energies



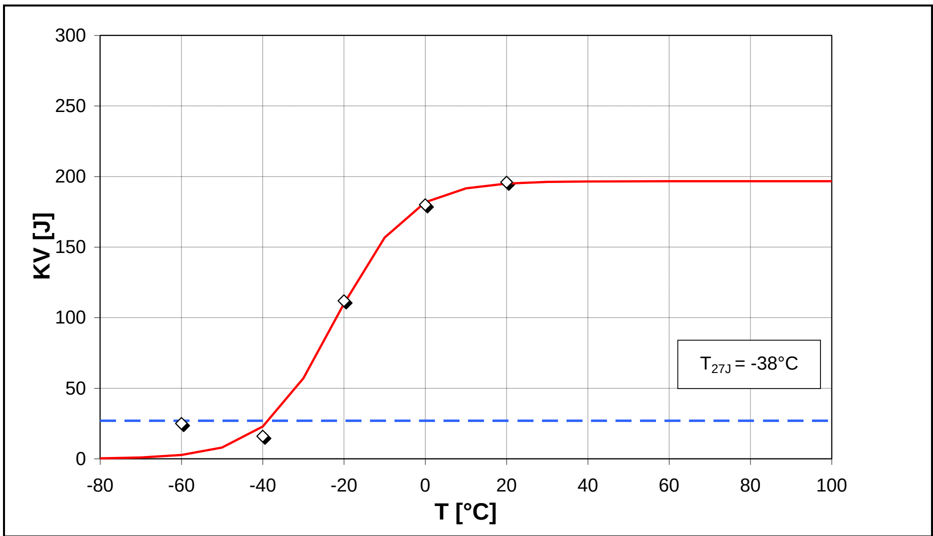
RHS 100x100x10 – plane area, longitudinal direction

$16\ J \le KV \le 67\ J$	
KV [J]	T_{27J} [°C]



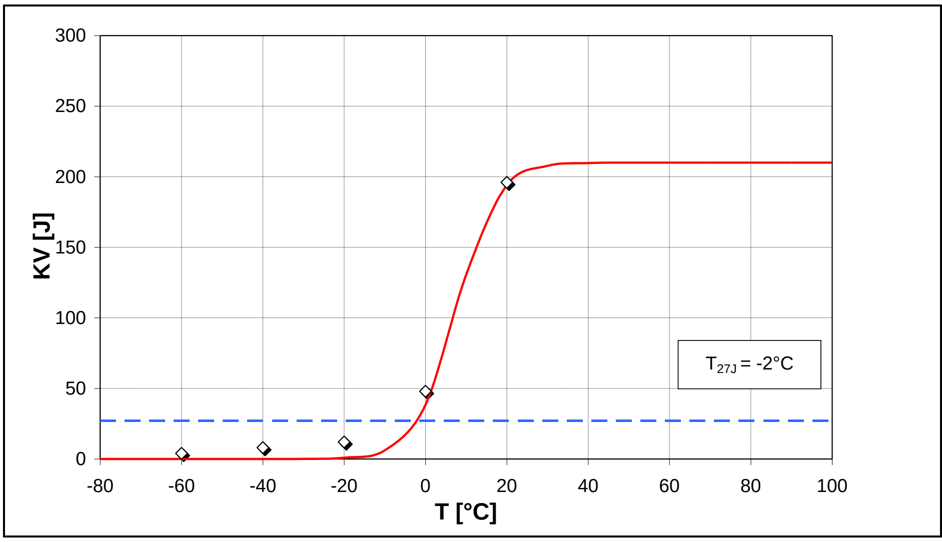
RHS 100x100x10 – plane area, transversal direction

$16\ J \le KV \le 67\ J$	
KV [J]	T_{27J} [°C]



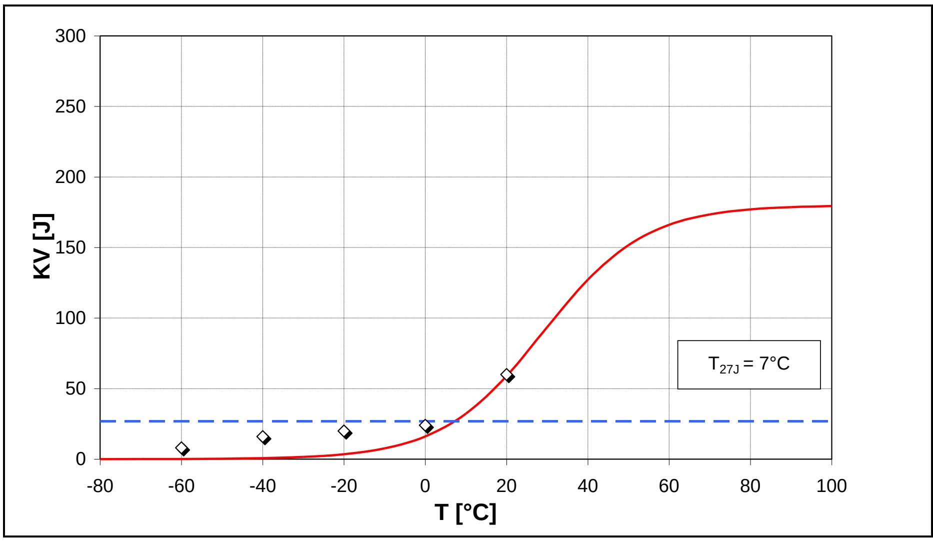
RHS 100x100x10 – bent area

$16\ J \le KV \le 67\ J$	
KV [J]	T_{27J} [°C]



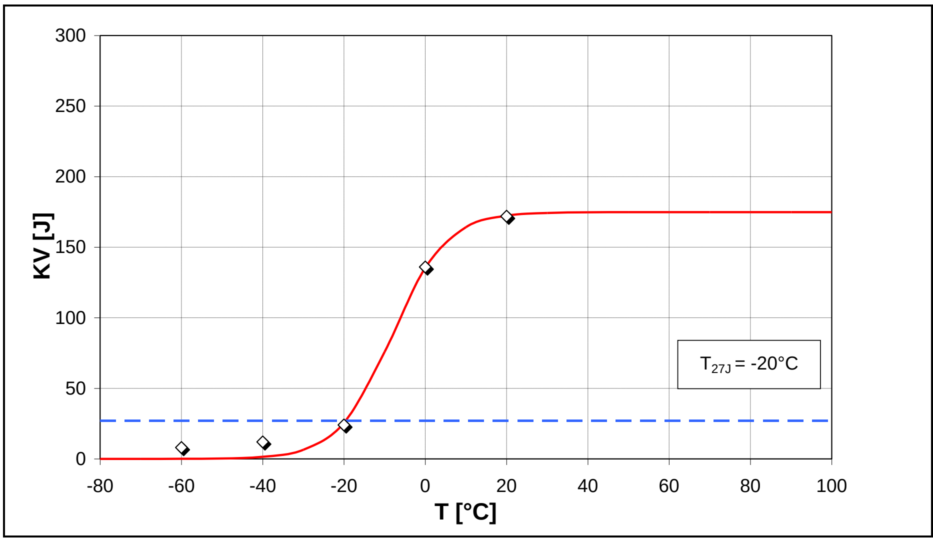
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 100x100x10 – plane area aged, longitudinal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 100x100x10 – plane area aged, transversal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 100x100x10 – bent area aged

No.24 Soininen-2 - RHS 150x150x8 (S355J2H acc. to EN 10219)

Delivered as grade S355J2H from European supplier A.

In the beginning of 1990's manufactured according to the then state of the art.

C-Mn-steels with some degree of micro-alloying.

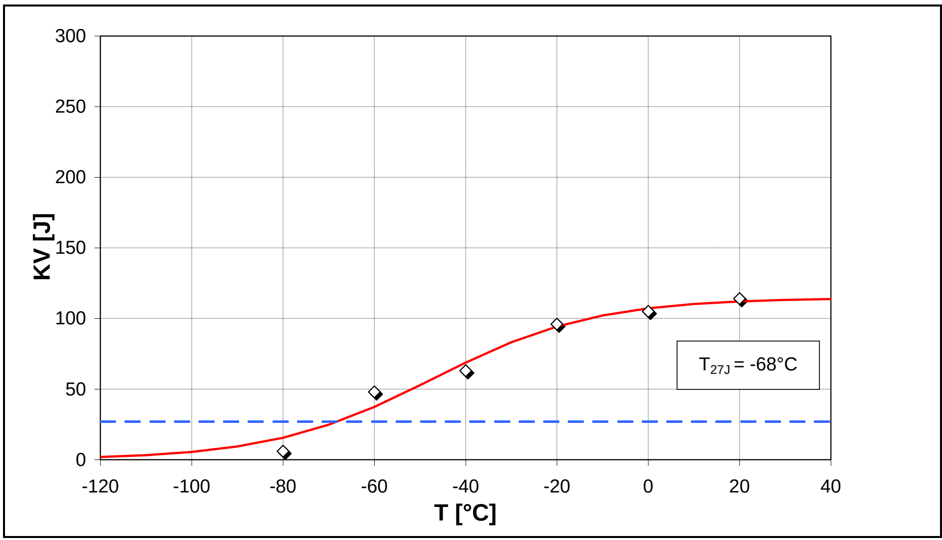
Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
150	150	8	20,0	12,0

Geometric dimensions of CVN-specimen

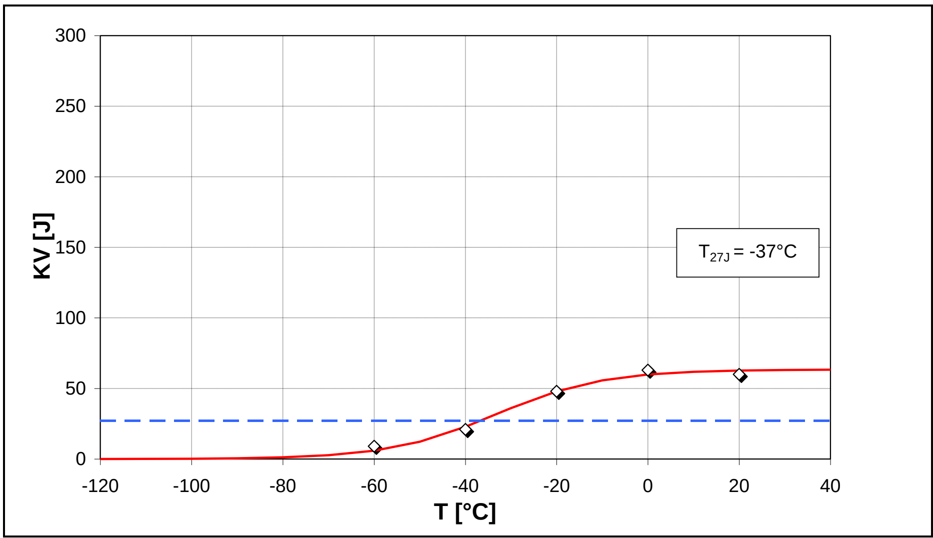
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	8	10	2	0,64	4,00

Impact energies



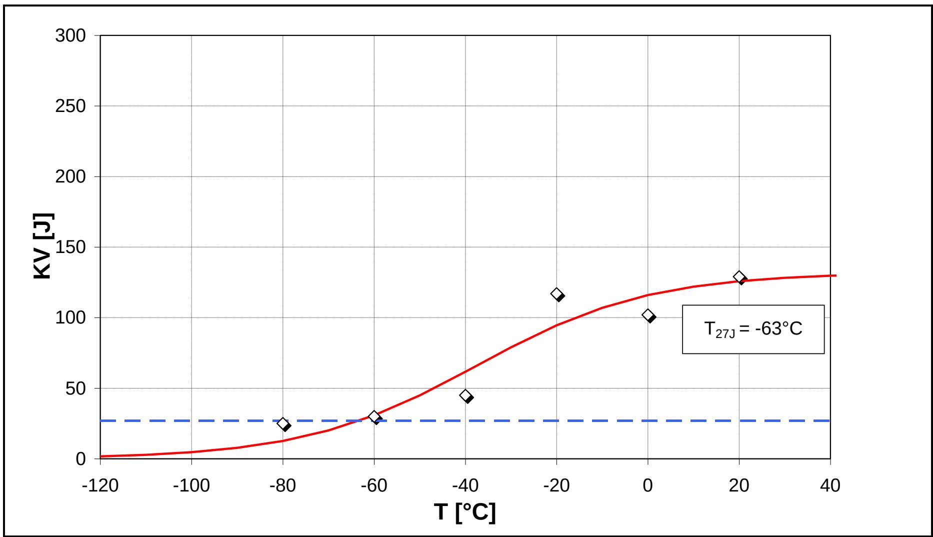
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 150x150x8 – plane area, longitudinal direction



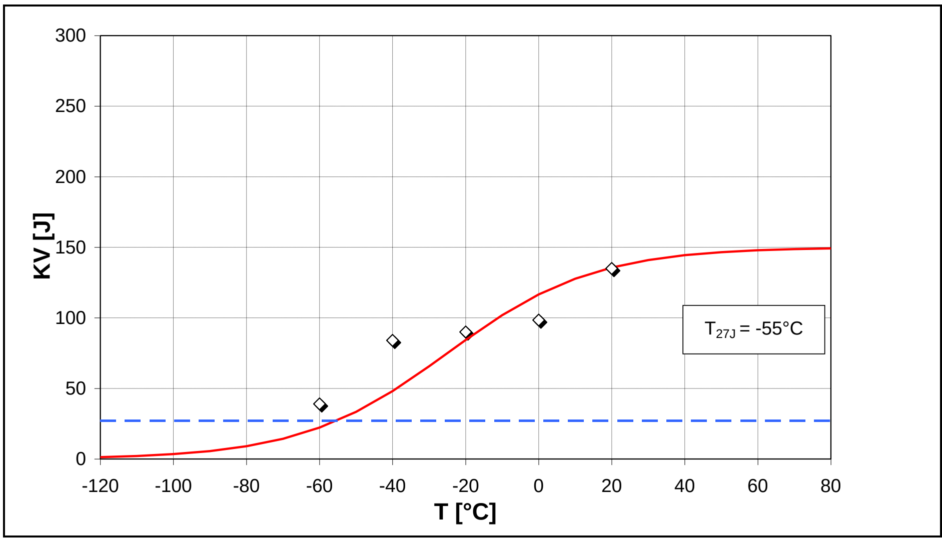
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 150x150x8 – plane area, transversal direction



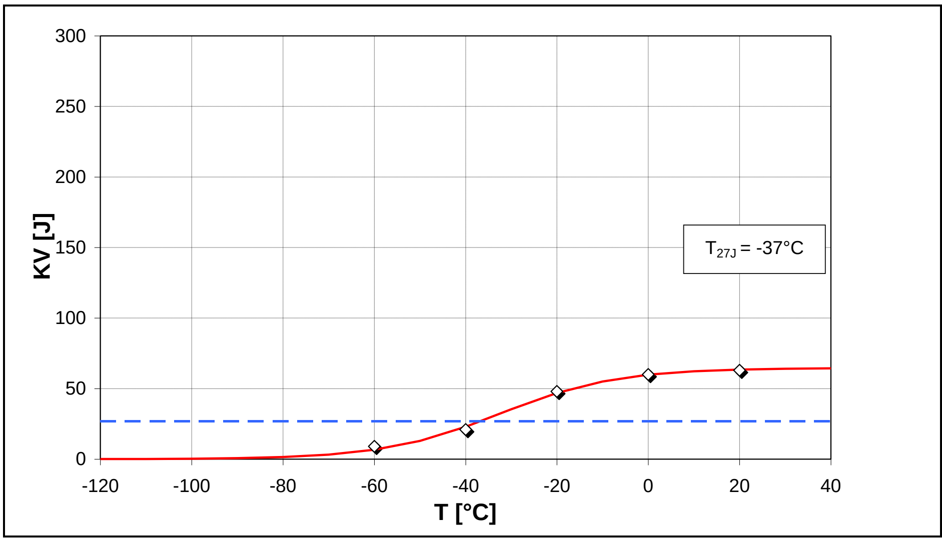
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 150x150x8 – bent area



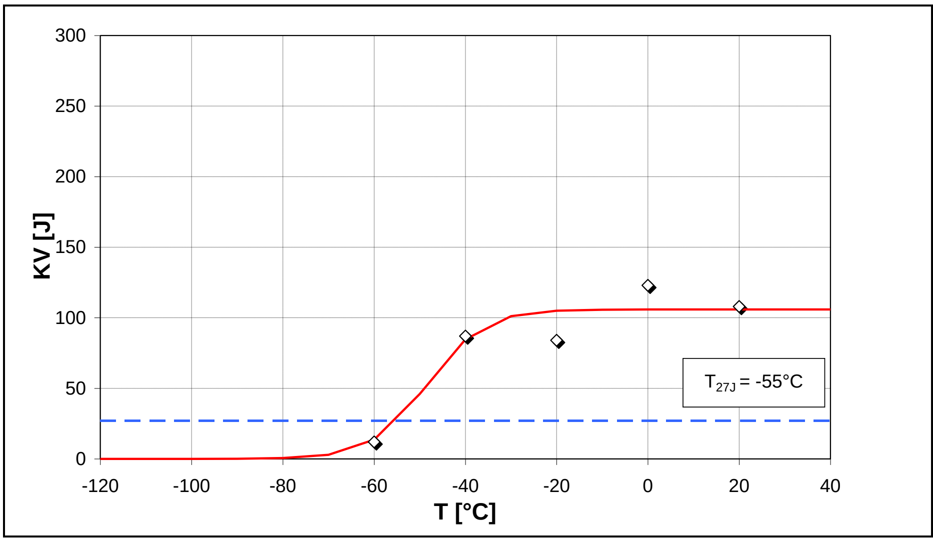
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 150x150x8 – plane area aged, longitudinal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 150x150x8 – plane area aged, transversal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 150x150x8 – bent area aged

No.25 Soininen-3 – RHS 200x200x12,5 (S355J2H acc. to EN 10219)

Delivered as grade S355J2H from European supplier A.

In the beginning of 1990's manufactured according to the then state of the art.

C-Mn-steels with some degree of micro-alloying.

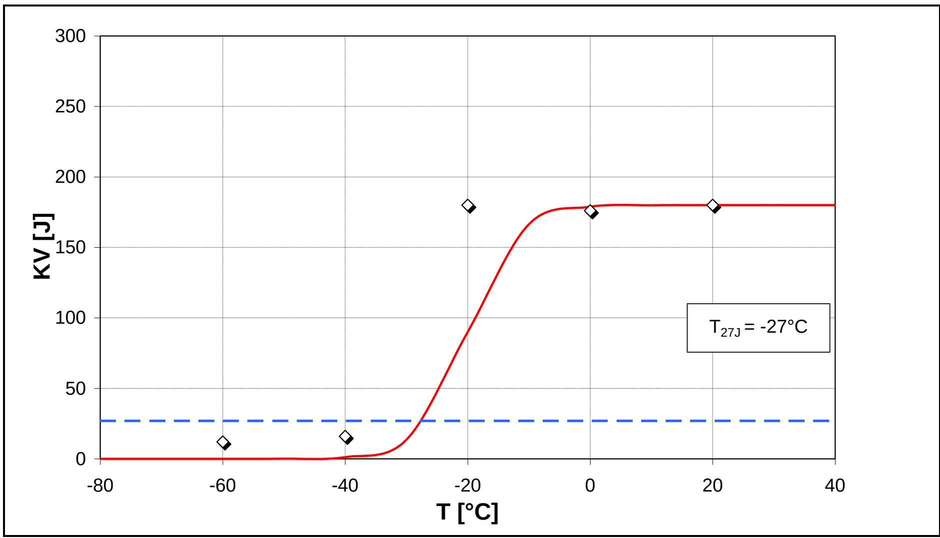
Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
200	200	12,5	37,5	25,0

Geometric dimensions of CVN-specimen

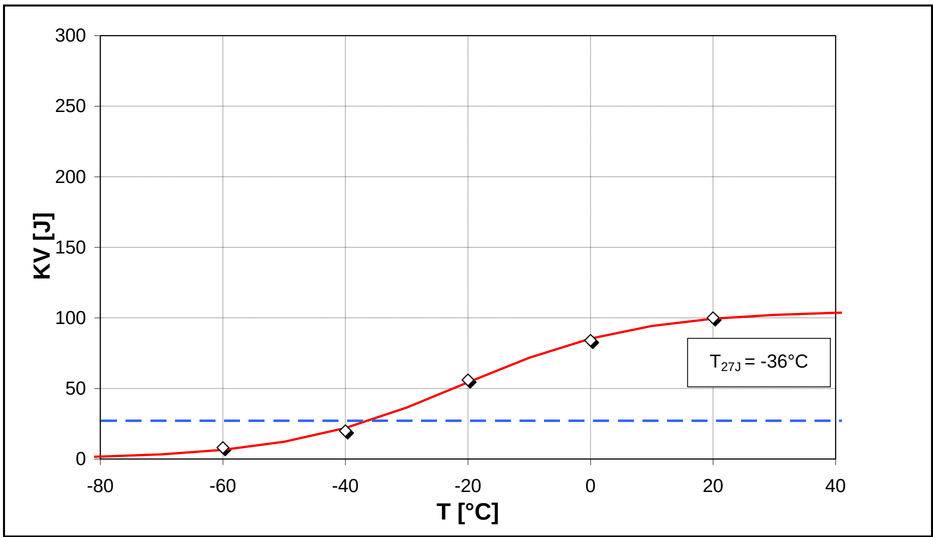
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	10	2	0,80	6,25

Impact energies



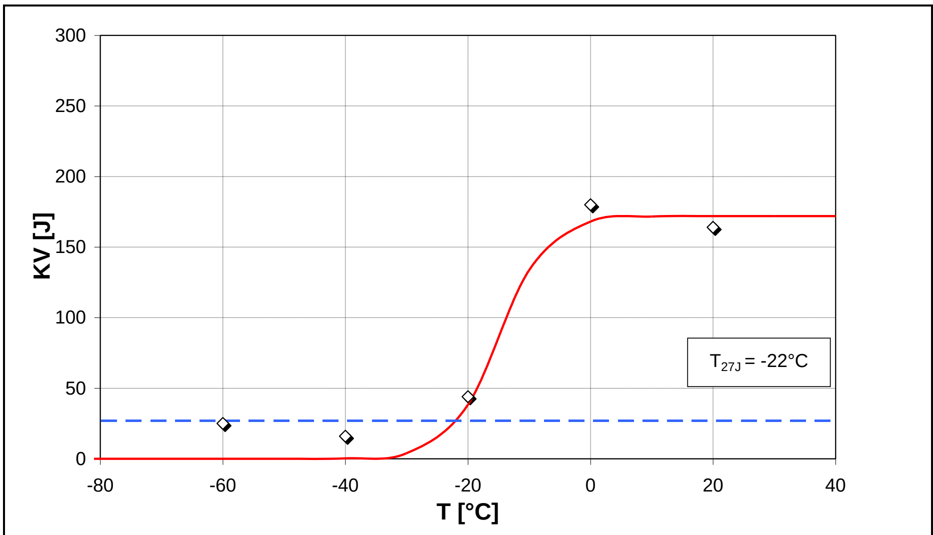
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 200x200x12,5 – plane area, longitudinal direction



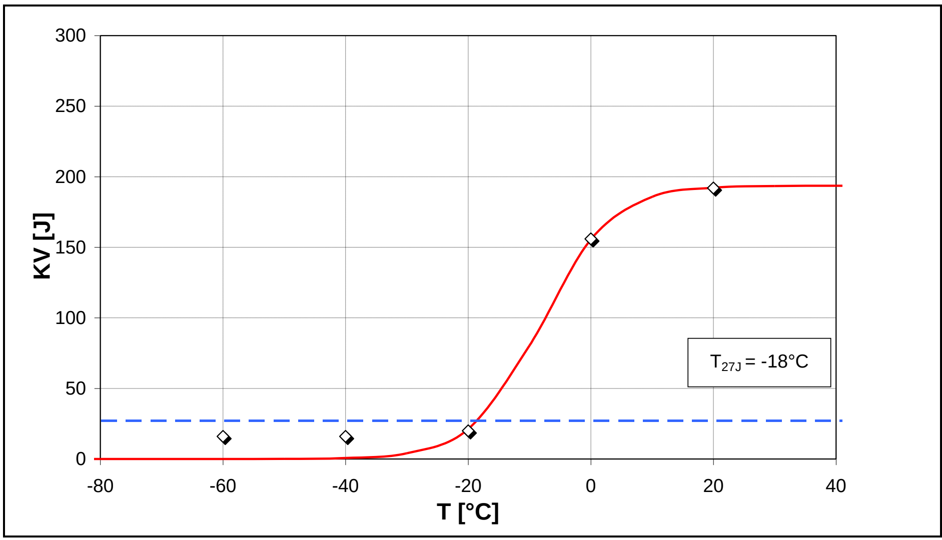
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 200x200x12,5 – plane area, transversal direction



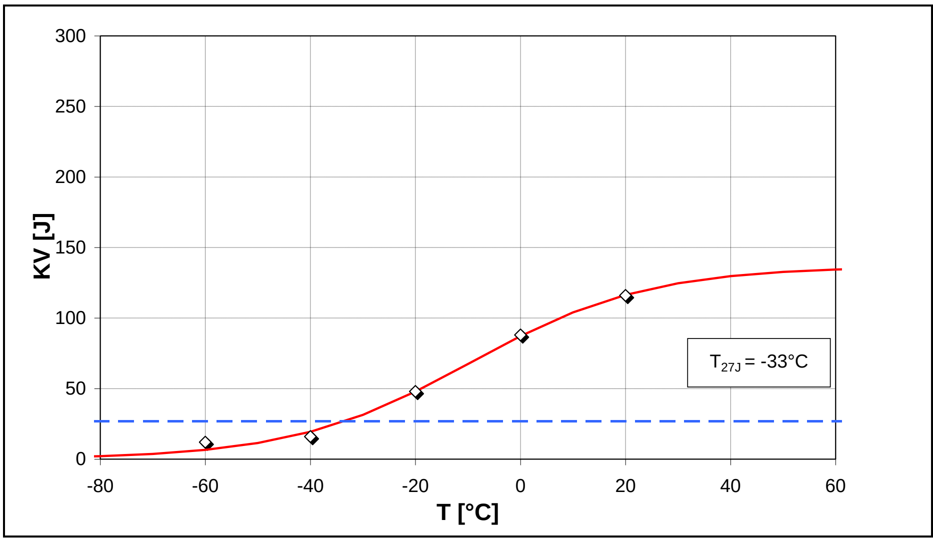
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 200x200x12,5 – bent area



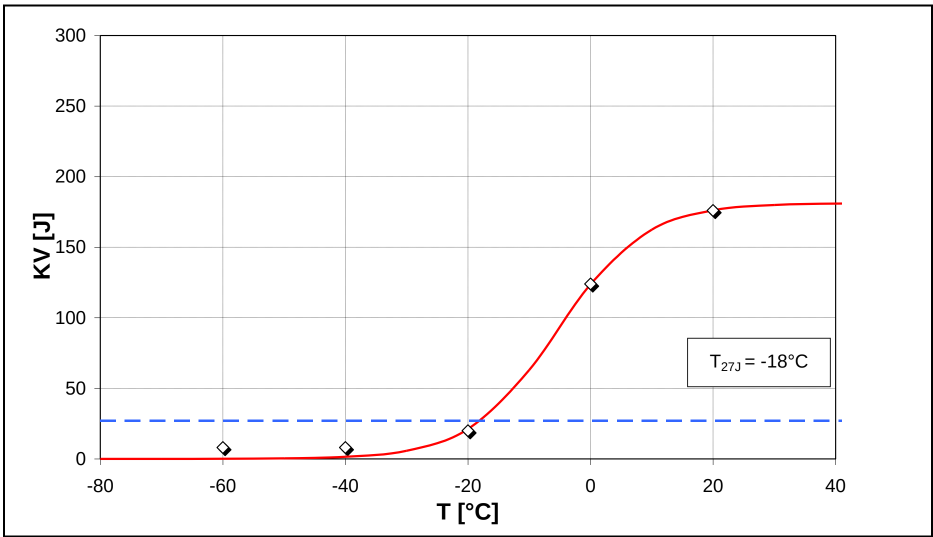
RHS 200x200x12,5 – plane area aged, longitudinal direction

16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]



RHS 200x200x12,5 – plane area aged, transversal direction

16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]



RHS 200x200x12,5 – bent area aged

16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

Annex A.2 Evaluation of test results (KV-values) with cold-formed hollow sections (circular)

No.		test no.	profile	profile dimensions D [mm]	d [mm]	t [mm]	r_i/t [-]	steel grade	production method	product standard
1	RUUKKI	Ruukki-5	273x10	273	253	10	12,65	S355J2H		EN 10219

Annex A.2.1 Results from RUUKKI – random sample taken from corner region [11]

Sampling:

(1) The position of the sampling layers is given in Figure A1-11. The width of the specimen was equal to the wall thickness of the tube. Notch position for the flat face was perpendicular to the surface in through-thickness direction.

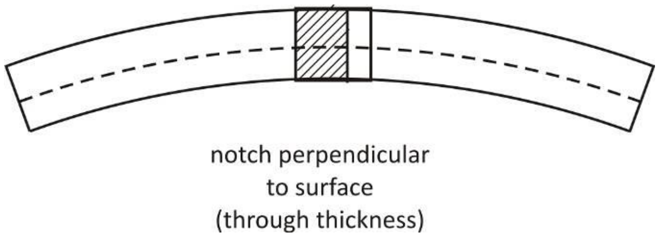


Figure A1-11: Position of Charpy-samples, flat face

No.1 Ruukki-5 - CHS 273x10 (S355J2H acc. to EN 10219)

Geometric dimensions of hollow section

D	d	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
273	253	10	136,5	126,5

Geometric dimensions of CVN-specimen

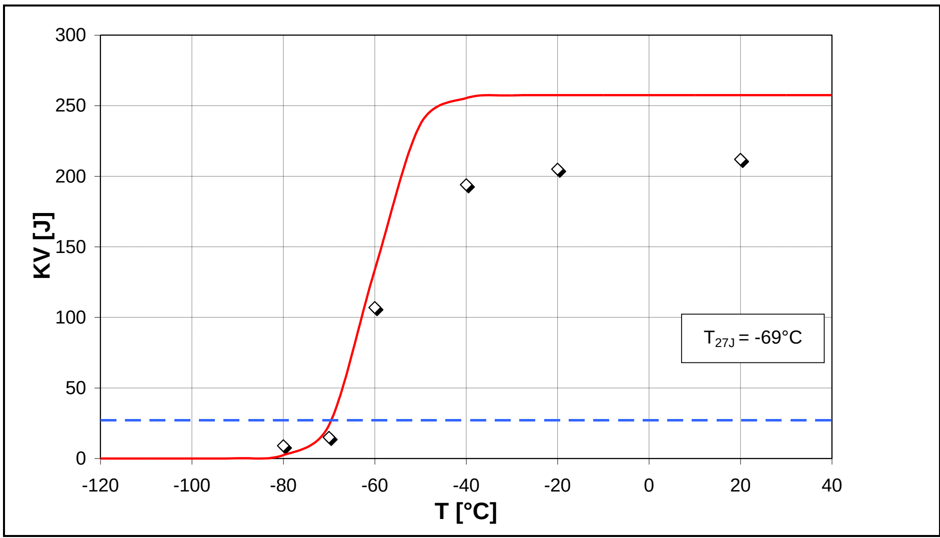
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	9,8	10	2	0,78	6,00

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,072	0,183	1,380	0,008	0,0042			0,033		

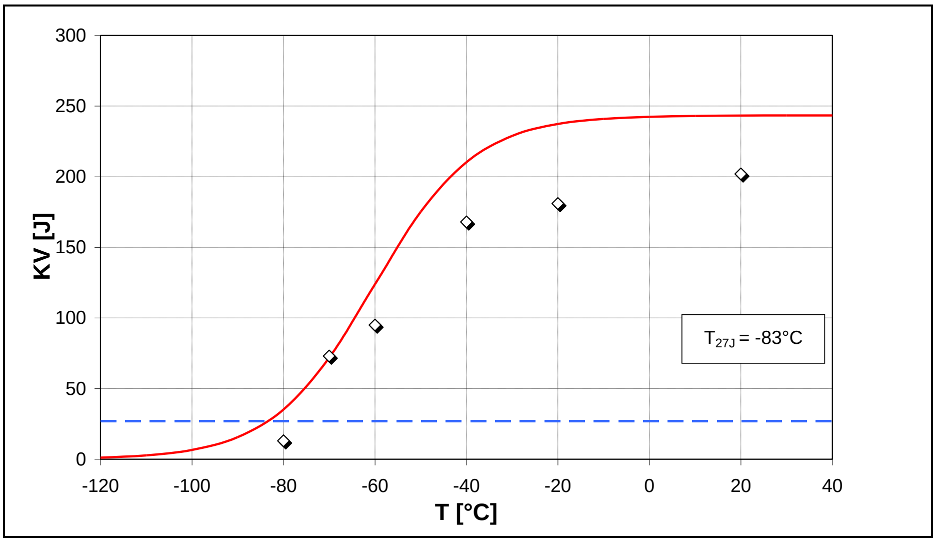
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
								0,0061			

Impact energies



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

CHS 273x10 – circular tube, longitudinal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

CHS 273x10 – circular tube, transversal direction

Annex A.3 Evaluation of test results (KV-values) with cold-formed, stress-relieved hollow sections

No.		test no.	profile	profile dimensions r_a [mm]	r_i [mm]	t [mm]	r_i/t [-]	steel grade	production method	product standard
1	CIDECT 1B	1B-5	305x305x12,7	25,4	12,7	12,7	1,0	A 500 B		ASTM A500B class H
2		1B-6	350x350x12,5	37,5	25,0	12,5	2,0	S355J2H		EN 10219

Annex A.3.1 Results from CIDECT 1B-report [15]

Sampling:

(1) Notch position was parallel to the surface as given in the following figures taken from the CIDECT 1B report.

No.1 1B-5 - RHS 305x305x12,7 (Steel equivalent to A500B ASTM A500-01, class H, stress relieved)

Delivered as grade A500B from Canadian supplier.

Traditional C-Mn-steels with C 0,18 % … 0,21 %.

Stress relieved at ~ 460 °C

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
305	305	12,7	25,4	12,7

Geometric dimensions of CVN-specimen

dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	10	2	0,80	

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,180	0,230	0,850	0,008	0,005					

Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV

Sampling according to Figure A3-1.

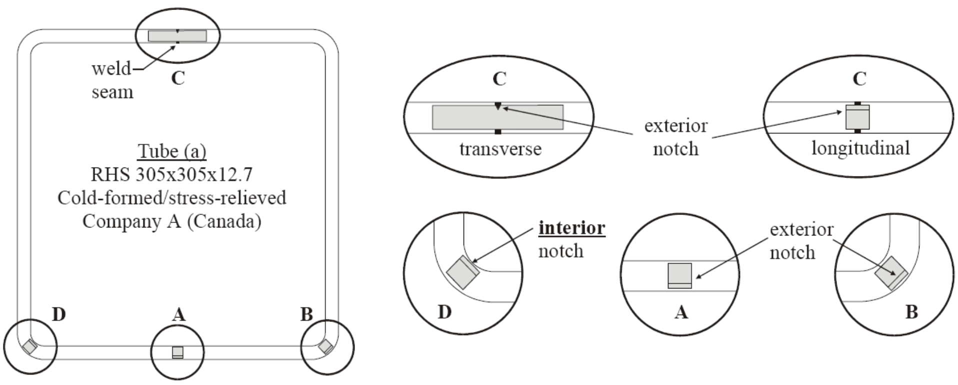
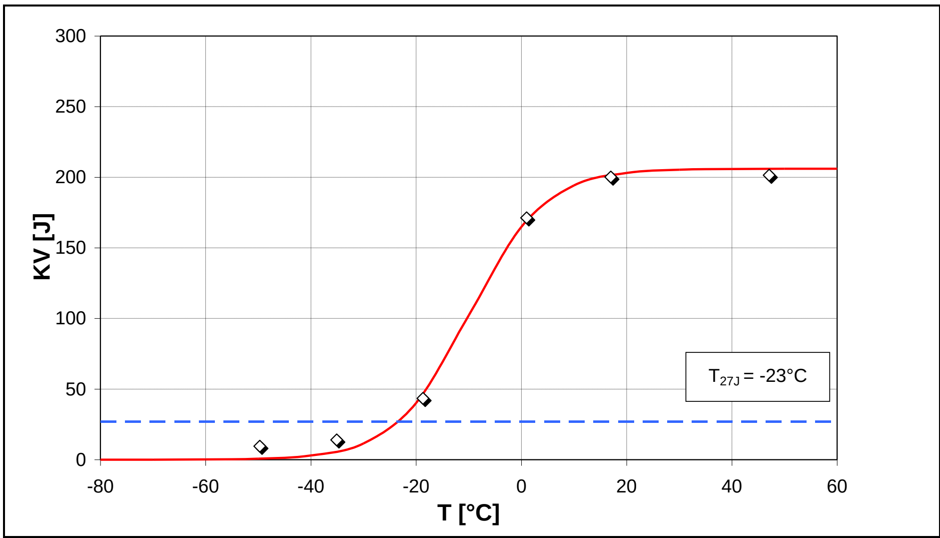


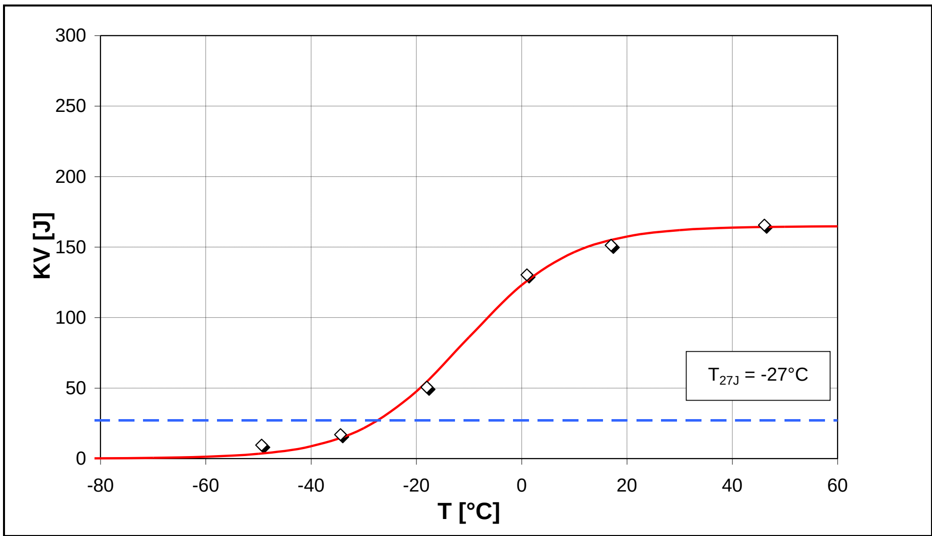
Figure A3-1: Position of Charpy-samples

Impact energies



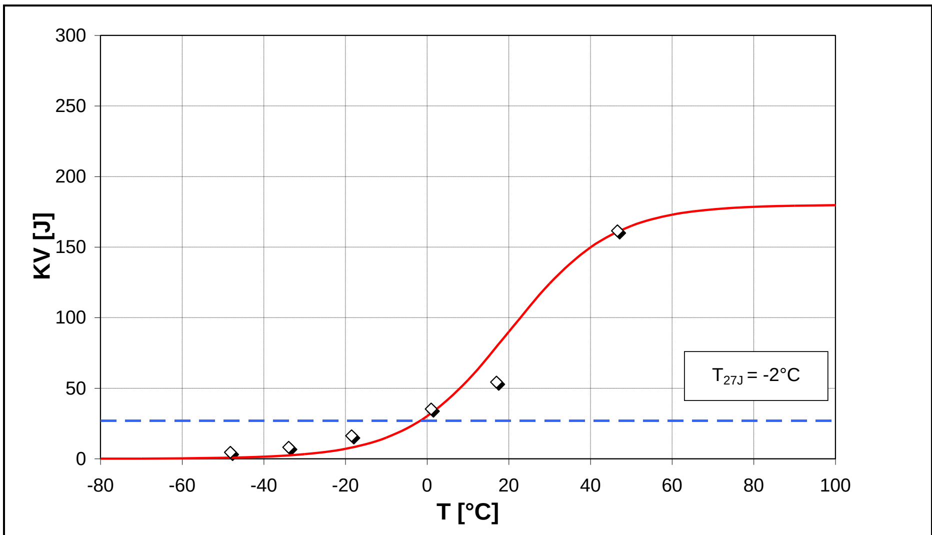
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
43	-19

RHS 305x305x12,7 – plane area, longitudinal direction



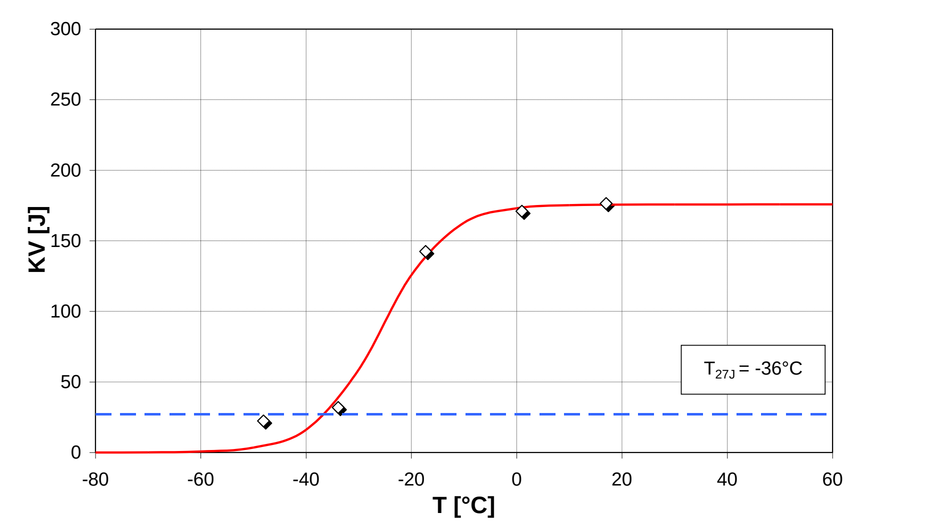
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
17	-25
51	-34

RHS 305x305x12,7 – bent area, outer notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
16	-9
35	-5
54	-1

RHS 305x305x12,7 – bent area, inner notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
22	-44
32	-38

RHS 305x305x12,7 – plane area, seam weld

No.2 1B-6 - RHS 350x350x12,5 (Steel S355J2H acc. to EN 10219, stress-relieved)

Delivered as grade S355J2H from French supplier.

C-Mn-steels with C 0,157 %

Stress relieved at ~ 460 °C

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
350	350	12,5	37,5	25,0

Geometric dimensions of CVN-specimen

dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	10	2	0,80	

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,157	0,190	1,345	0,014	0,008	0,020	0,000	0,036	0,030	0,010

Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,020	0,000	0,017	0,000					0,002			

Sampling according to Figure A3-2.

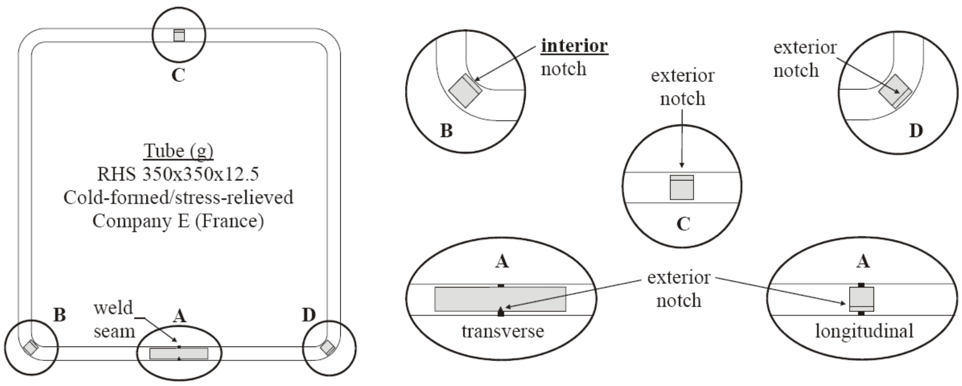
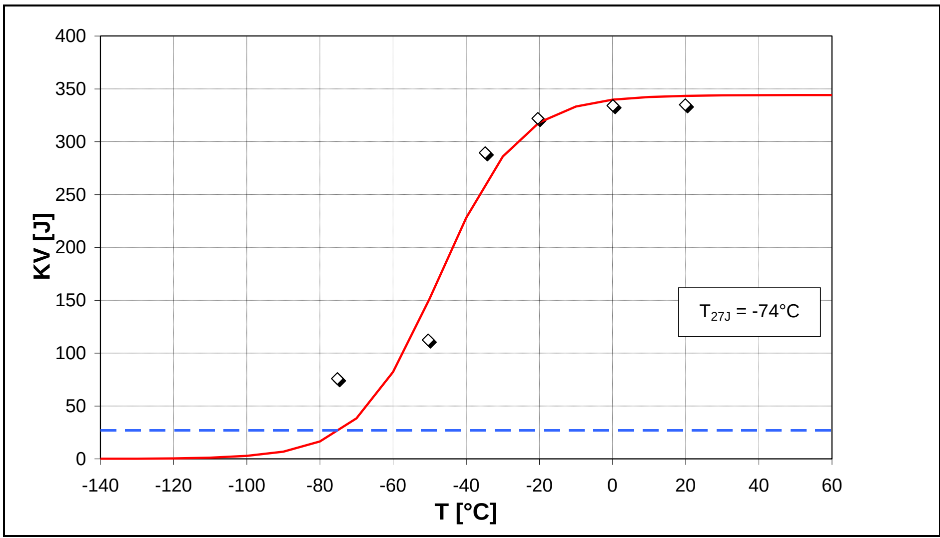


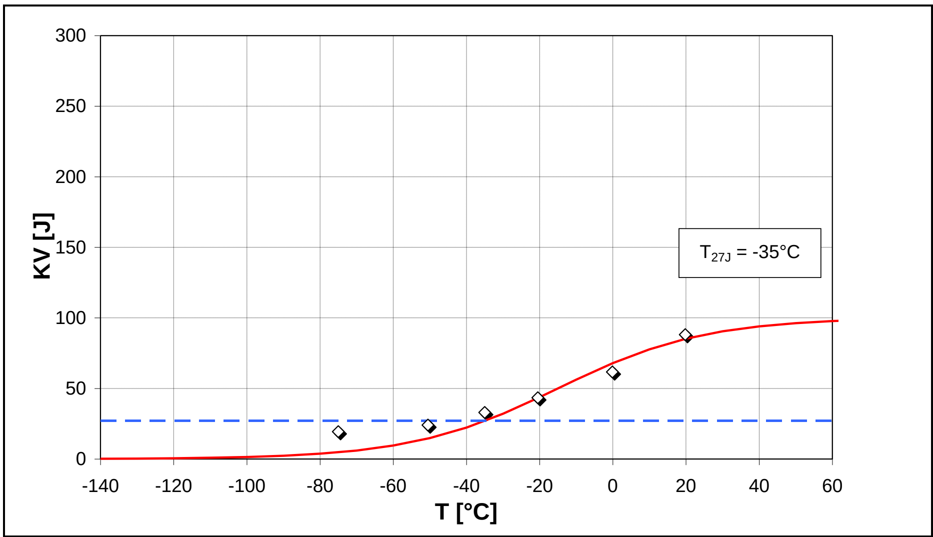
Figure A3-2: Position of Charpy-samples

Impact energies



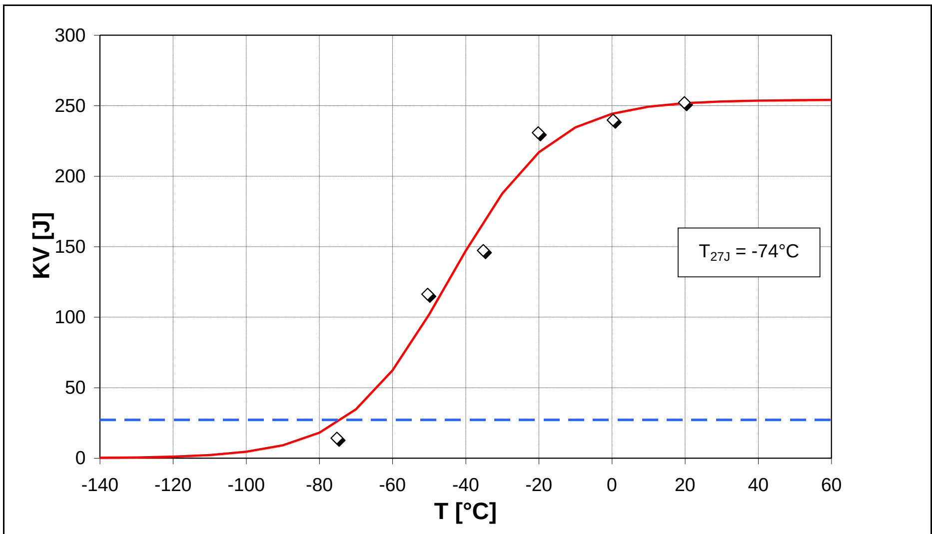
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 350x350x12,5 – plane area, longitudinal direction



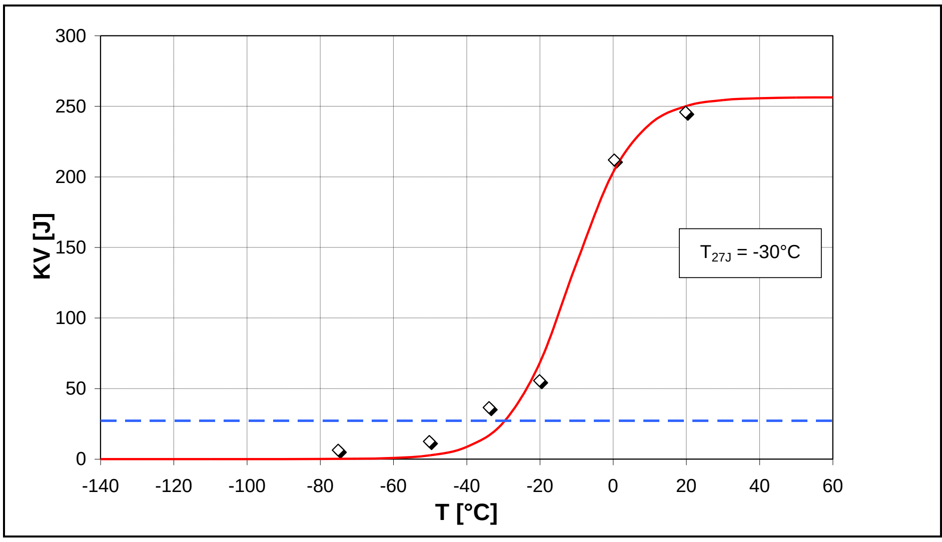
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
19	-68
24	-48
33	-40
43	-32
62	-22

RHS 350x350x12,5 – plane area, transversal direction



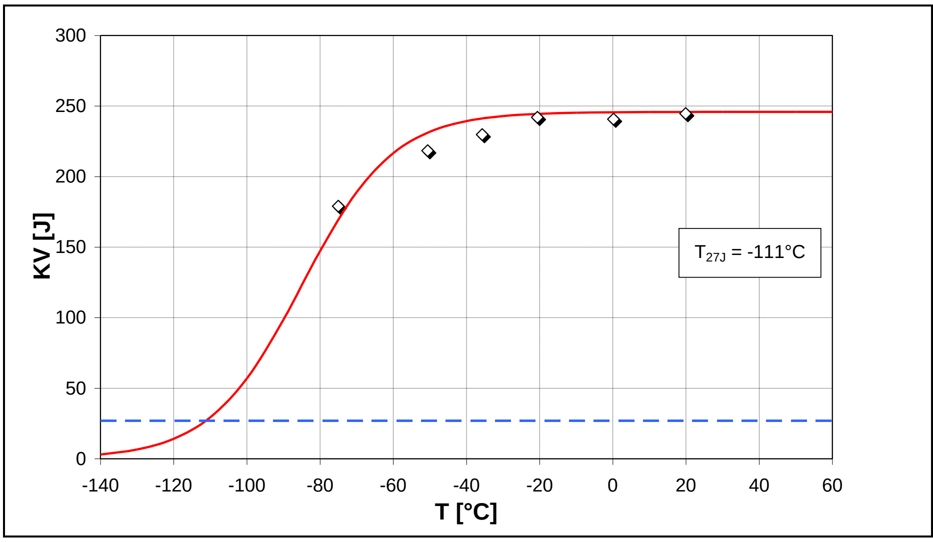
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 350x350x12,5 – bent area, outer notch



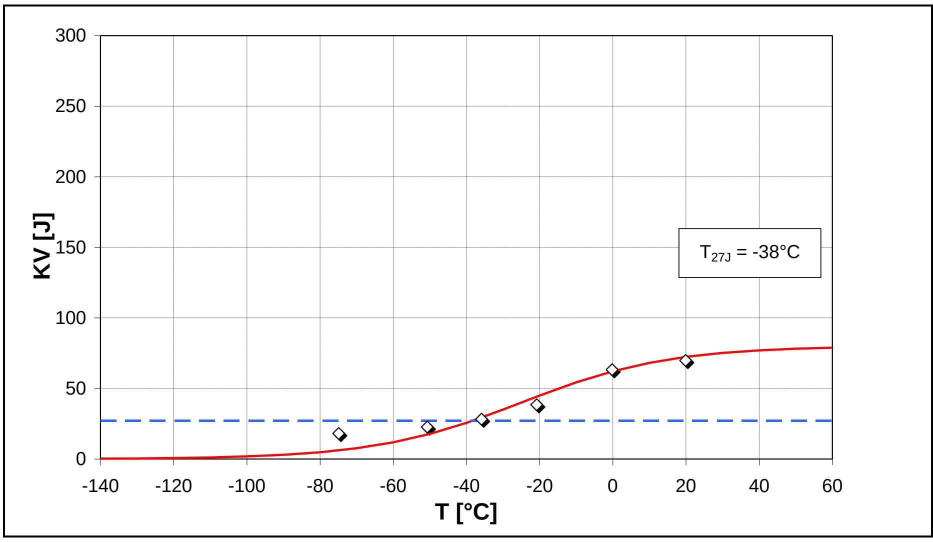
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
37	-41
56	-39

RHS 350x350x12,5 – bent area, inner notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 350x350x12,5 – seam weld, longitudinal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
18	-67
23	-47
28	-37
38	-29
63	-23

RHS 350x350x12,5 – seam weld, transversal direction

Annex A.4 Evaluation of test results (KV-values) with hot-rolled hollow sections

Rectangular sections

No.		test no.	profile	profile dimensions r_a [mm]	r_i [mm]	t [mm]	r_i/t [-]	steel grade	production method	product standard
1	CIDECT 1B	1B-7	100x100x12,5	18,75	12,5	12,5	1,0	S355J2H		EN 10210
2	V & M	Ham 12,5	400x400x12,5	18,75	12,5	12,5	1,0	S355J2H		EN 10210
3		Ham 16,0	400x300x16,0	24,0	16,0	16,0	1,0	S355J2H		
4		Ham 20,0	500x300x20,0	30,0	20,0	20,0	1,0	S355J2H		
5		D 12,5	180x180x12,5	18,75	12,5	12,5	1,0	S355J2H		
6		D 16,0	250x150x16,0	24,0	16,0	16,0	1,0	S355J2H		
7		D 17,5	200x200x17,5	26,25	17,5	17,5	1,0	S355J2H		
8		D 20,0	300x300x20,0	30,0	20,0	20,0	1,0	S355J2H		
9		Mh 11,0	120x120x11,0	16,5	11,0	11,0	1,0	S355J0H		

Circular sections

No.		test no.	profile	profile dimensions r_a [mm]	r_i [mm]	t [mm]	r_i/t [-]	steel grade	production method	product standard
10	CIDECT 1B	1B-8	324x8,4	324	307,2	8,4	36,6	A 53 B		ASTM A53B A53M-01

Annex A.4.1 Results from CIDECT 1B-report [15], rectangular sections

Sampling:

(1) Notch position was parallel to the surface as given in the following figures taken from the CIDECT 1B report.

No.1 1B-7 - RHS 100x100x12,5 (S355J2H acc. to EN 10210)

Delivered as grade S355J2H from German supplier.

C-Mn-steels with C 0,16 %

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
100	100	12,5	18,75	12,5

Geometric dimensions of CVN-specimen

dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	10	2	0,80	

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,160	0,230	1,350	0,015	0,002			0,038		

Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
	0,040										

Sampling according to Figure A4- 1.

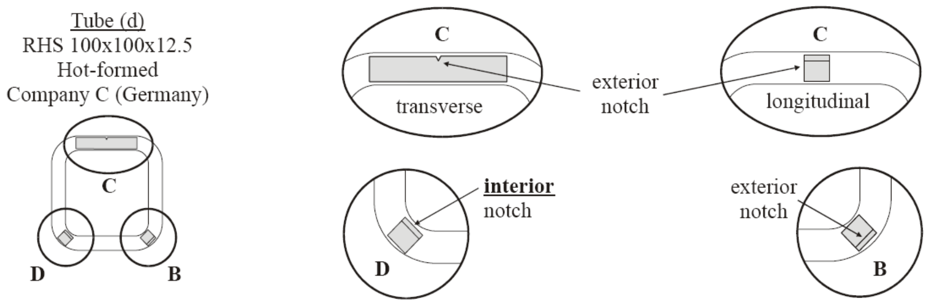
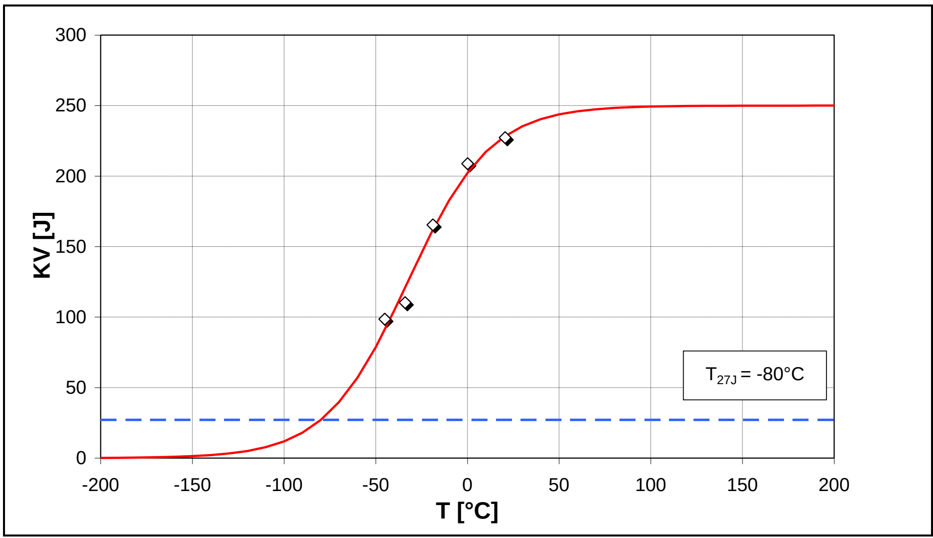


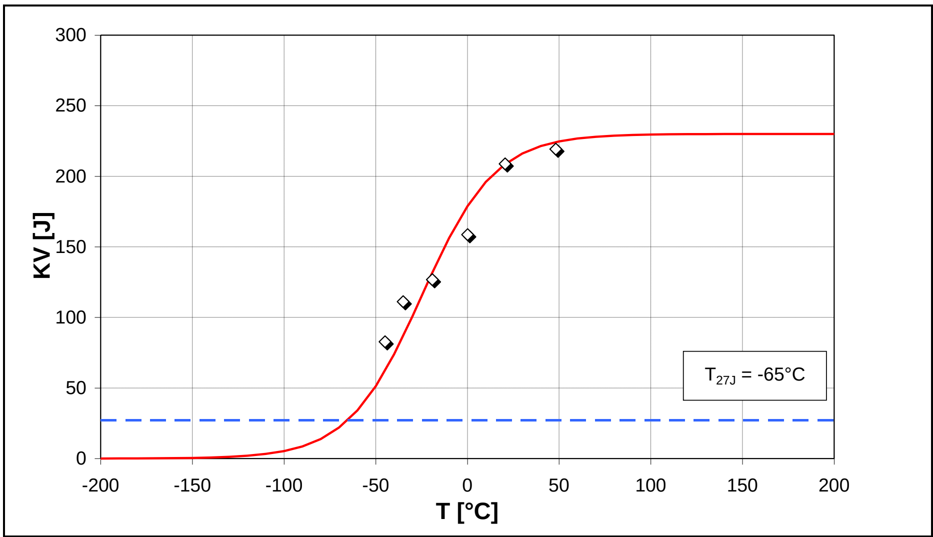
Figure A4- 1: Position of Charpy-samples

Impact energies



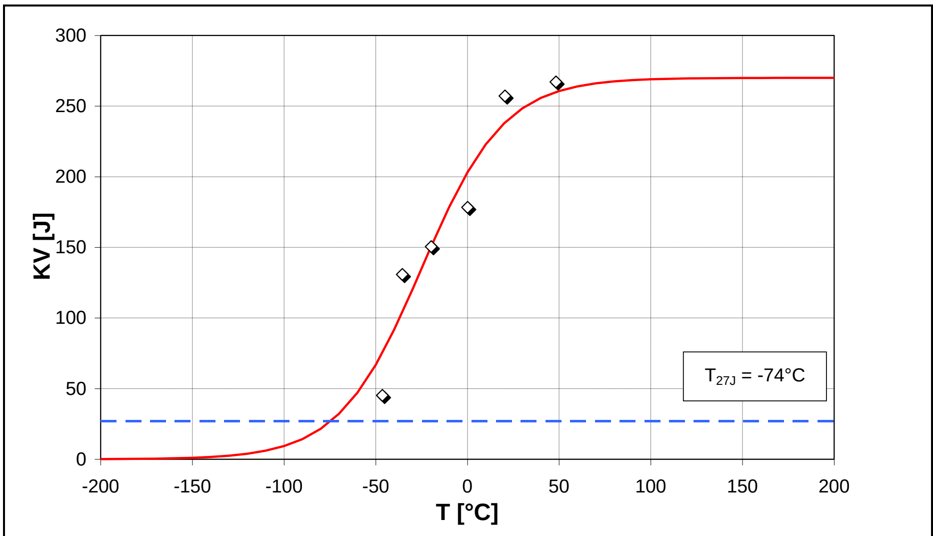
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 100x100x12,5 – plane area, longitudinal direction



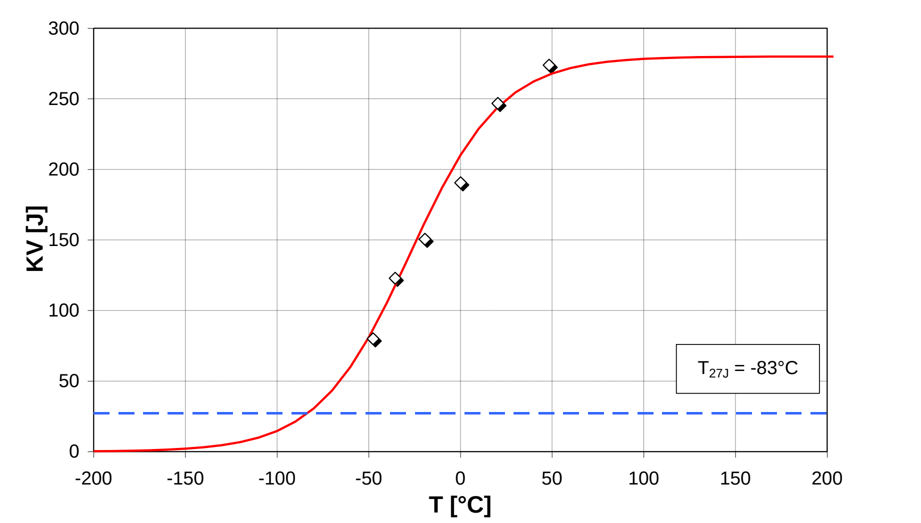
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 100x100x12,5 – plane area, transversal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
45	-59

RHS 100x100x12,5 – corner area, outer notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 100x100x12,5 – corner area, inner notch

Annex A.4.2 Results from V & M Steel [16]

Sampling:

(1) The position of the sampling layers is given in Figure A4- 2. The width of the specimen was 10 mm for t > 10 mm. Notch position for the flat face and the corner area were parallel to the surface.

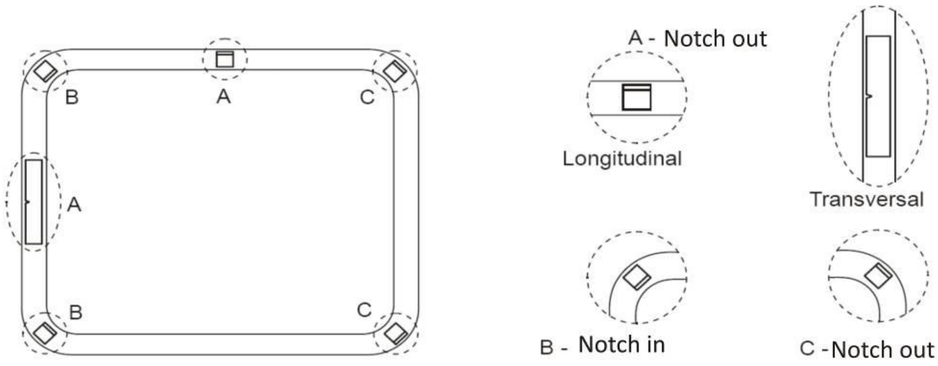


Figure A4- 2: Position of Charpy-samples, flat face

<u>No.2 V&M Ham 12,5 - RHS 400x400x12,5 (S355J2H acc. to EN 10210)</u>

Delivered as grade S355J2H from German supplier (V & M Tubes Hamm).

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
400	400	12,5	18,75	12,5

Geometric dimensions of CVN-specimen

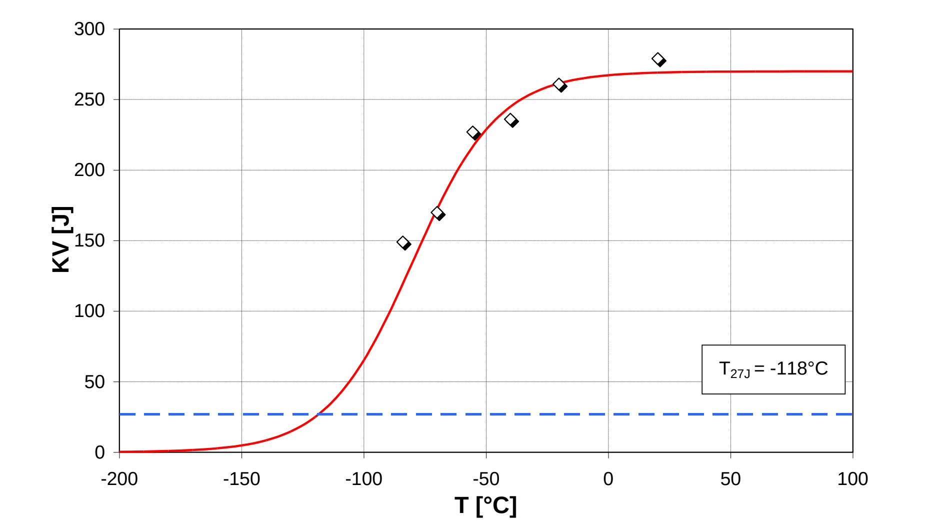
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	10	2	0,80	7,25

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,150	0,000	1,400	0,018	0,003	0,034		0,034	0,080	0,010

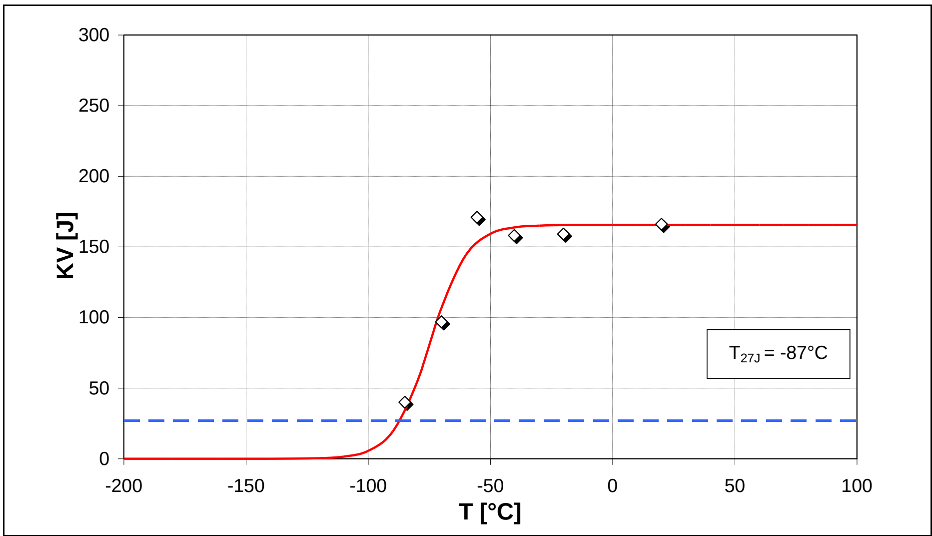
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,040	0,000	0,004	0,024			0,0003		0,0045			0,41

Impact energies



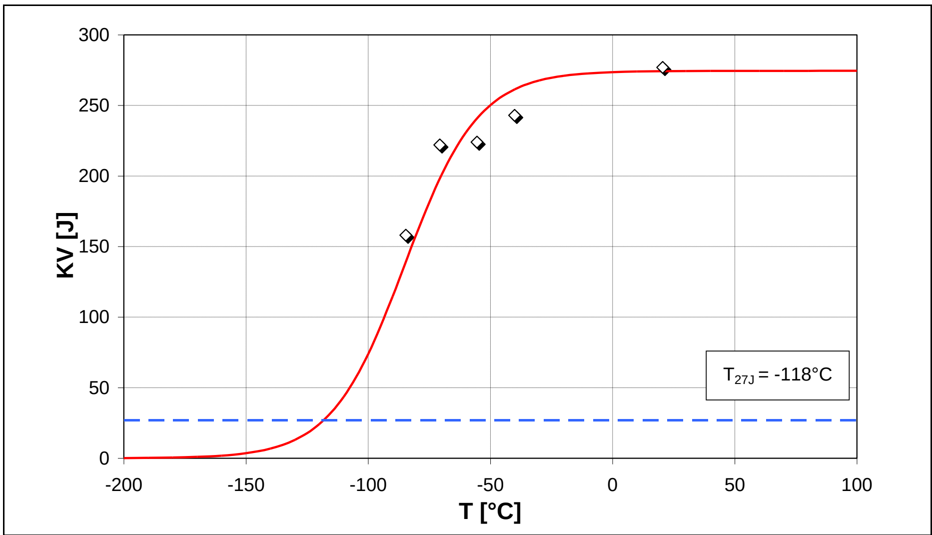
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 400x400x12,5 – plane area, transversal direction



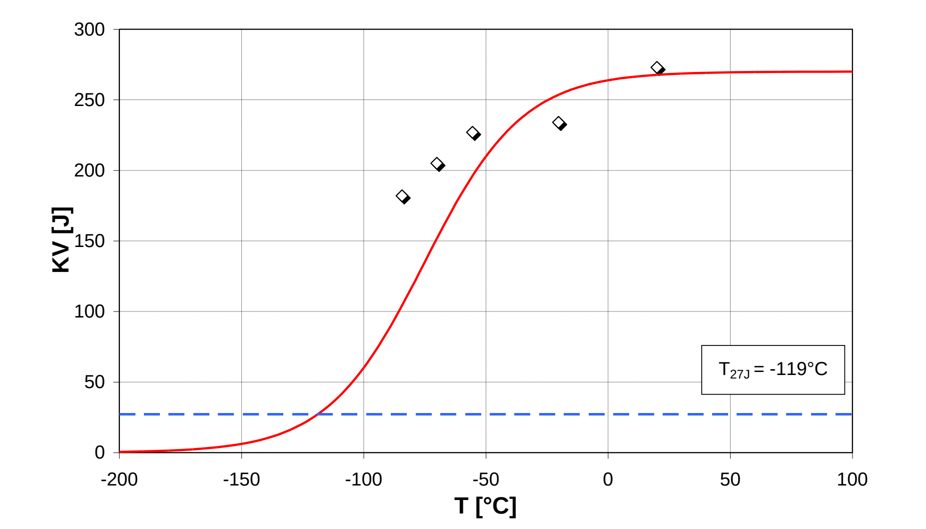
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
40	-94

RHS 400x400x12,5 – plane area, transversal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 400x400x12,5 – corner area, inner notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 400x400x12,5 – corner area, outer notch

No.3 V&M Ham 16,0 - RHS 400x300x16,0 (S355J2H acc. to EN 10210)

Delivered as grade S355J2H from German supplier (V & M Tubes Hamm).

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
400	300	16,0	24,0	16,0

Geometric dimensions of CVN-specimen

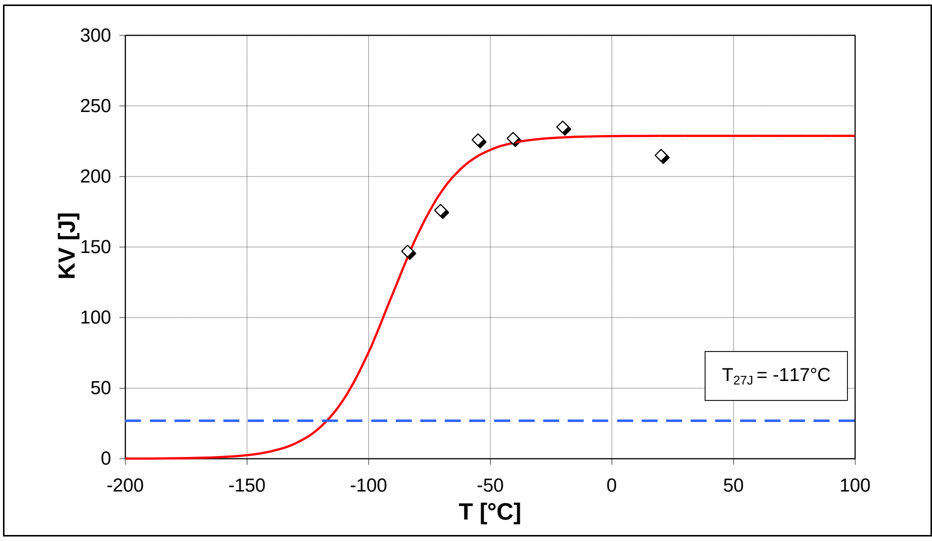
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	10	2	0,80	9,00

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,150	0,190	1,410	0,013	0,001	0,030		0,038	0,080	0,010

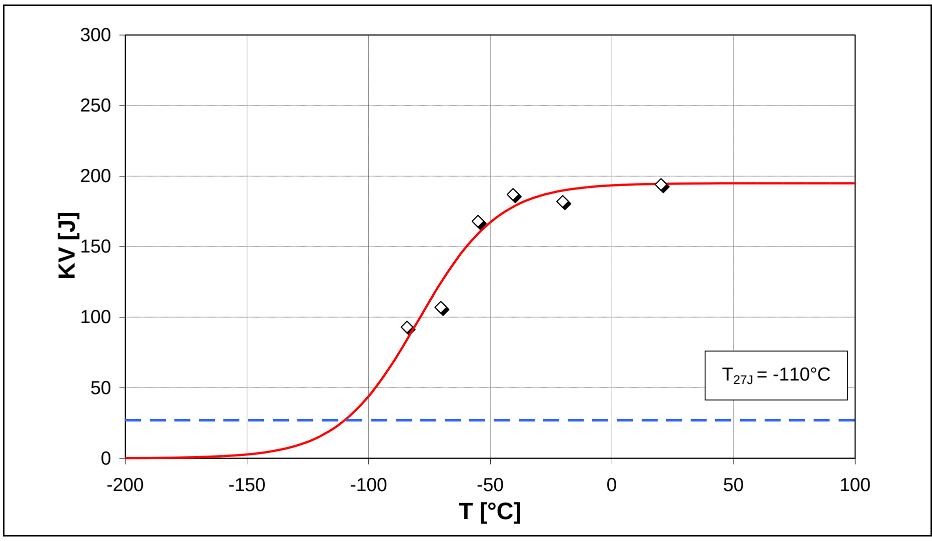
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,050	0,000	0,005	0,023		0,0002			0,004			0,4

Impact energies



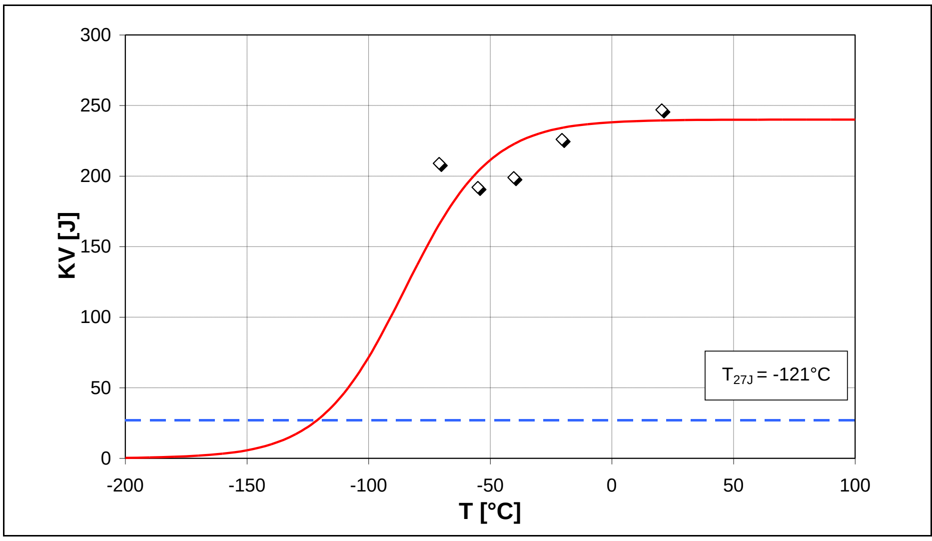
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 400x300x16,0 – plane area, longitudinal direction



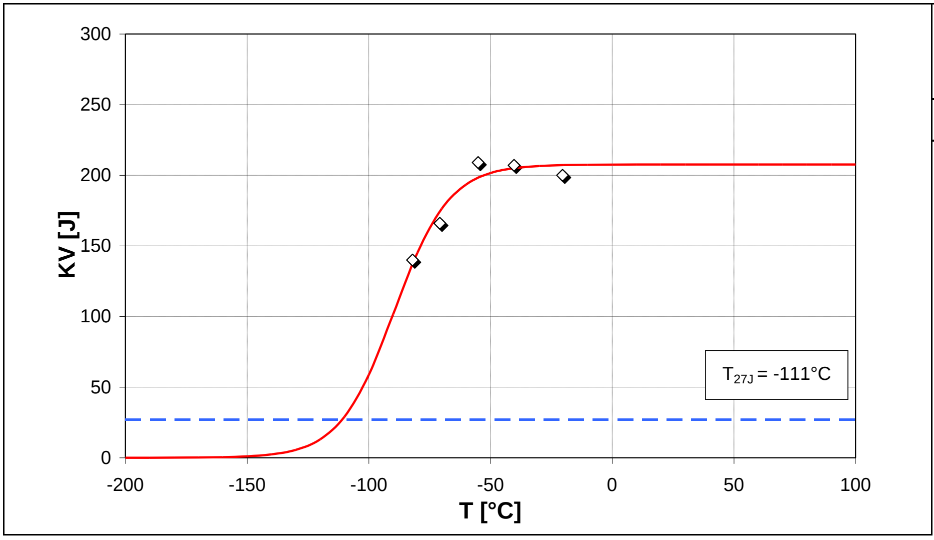
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 400x300x16,0 – plane area, transversal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 400x300x16,0 – corner area, inner notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 400x300x16,0 – corner area, outer notch

No.4 V&M Ham 20,0 - RHS 500x300x20,0 (S355J2H acc. to EN 10210)

Delivered as grade S355J2H from German supplier (V & M Tubes Hamm).

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
500	300	20,0	30,0	20,0

Geometric dimensions of CVN-specimen

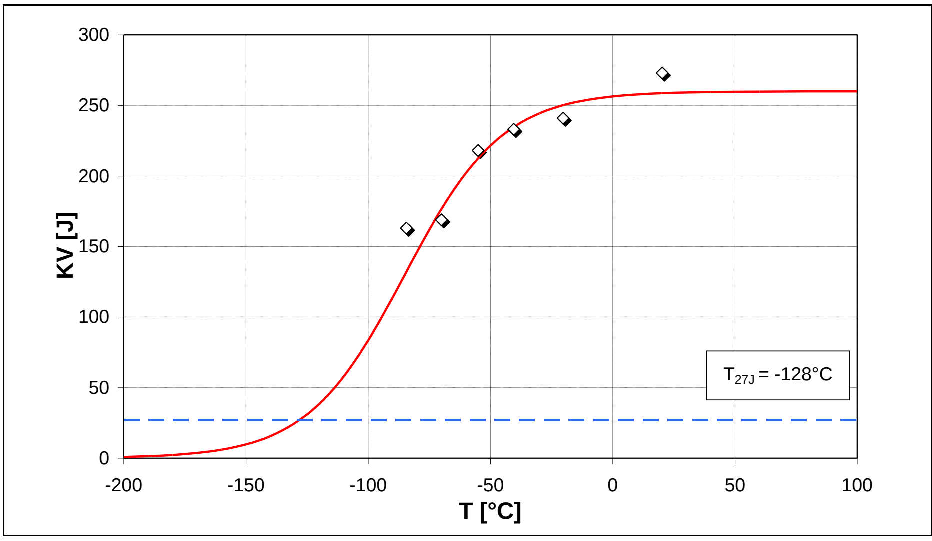
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	10	2	0,80	11,0

Chemical analysis

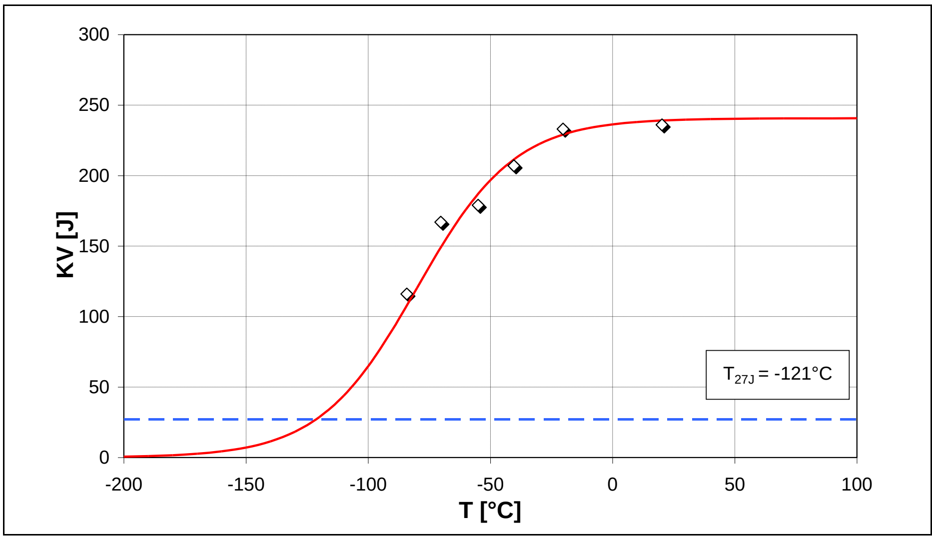
C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,150	0,180	1,350	0,015	0,001	0,050		0,029	0,080	0,000

Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,040	0,000	0,004	0,025		0,000			0,0049			0,4

Impact energies

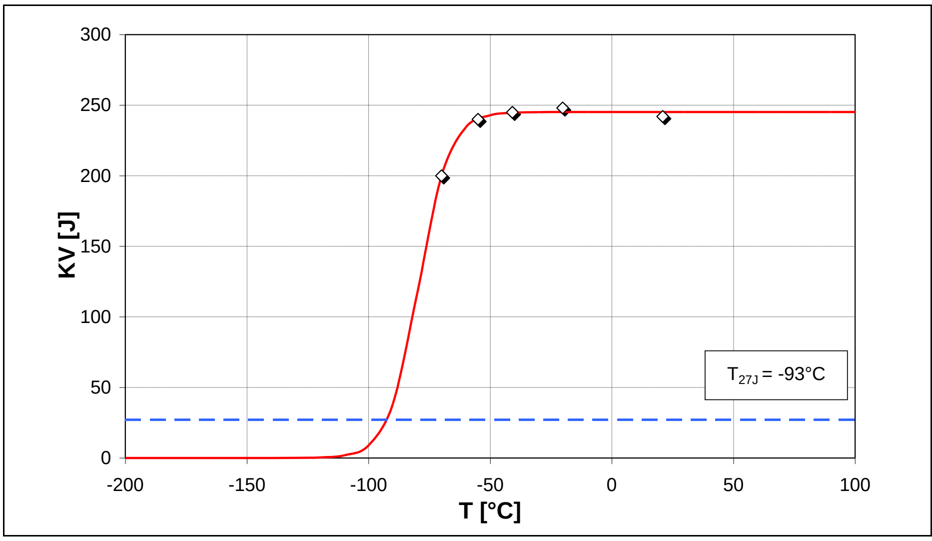


16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]



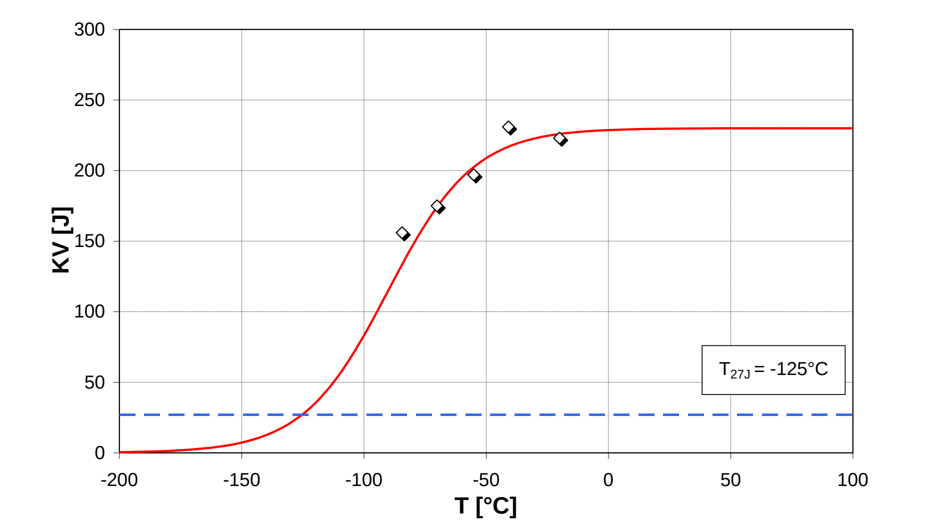
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 500x300x20,0 – plane area, transversal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 500x300x20,0 – corner area, inner notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 500x300x20,0 – corner area, outer notch

No.5 V&M D 12,5 - RHS 180x180x12,5 (S355J2H acc. to EN 10210)

Delivered as grade S355J2H from German supplier (V & M Tubes Düsseldorf).

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
180	180	12,5	18,75	12,5

Geometric dimensions of CVN-specimen

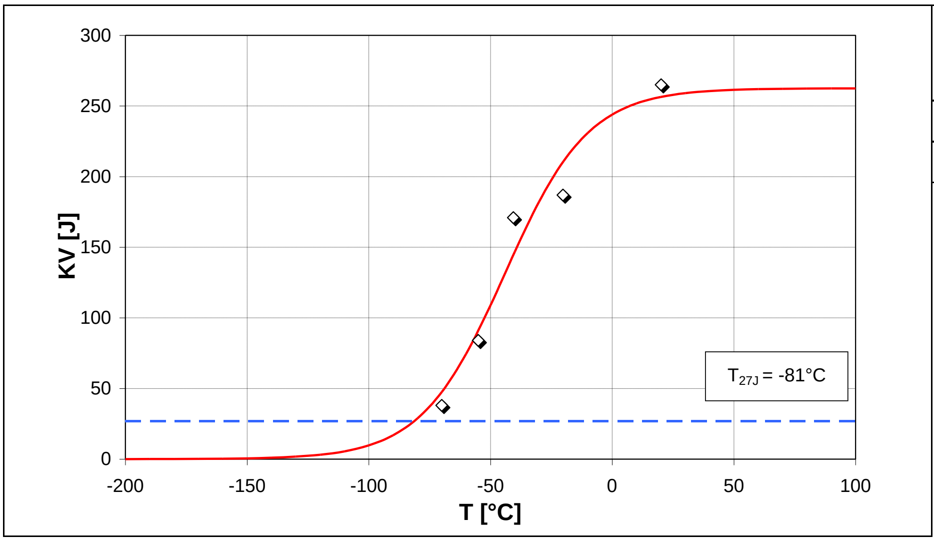
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	10	2	0,80	7,25

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,140	0,170	1,390	0,0150	0,001	0,002		0,037	0,050	0,010

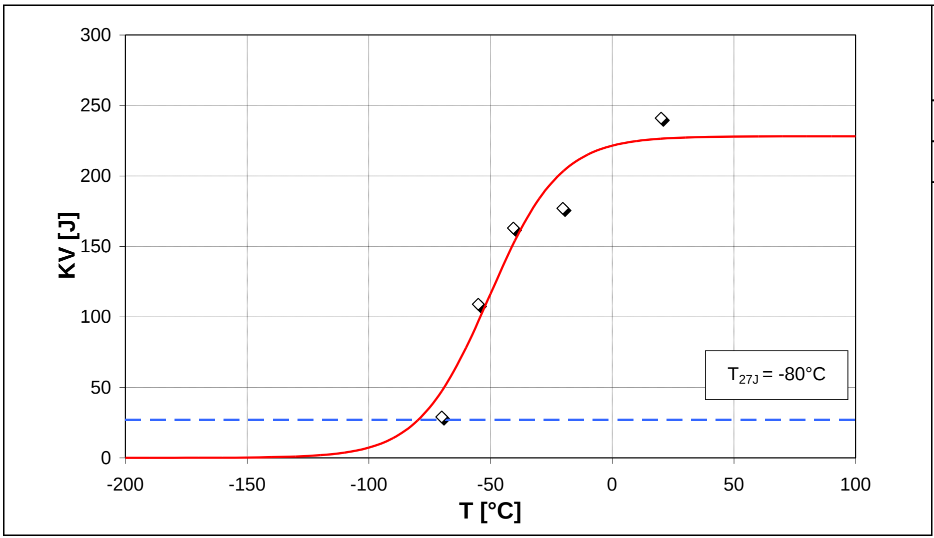
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,030	0,060	0,0040	0,001		0,0003			0,0094			0,40

Impact energies



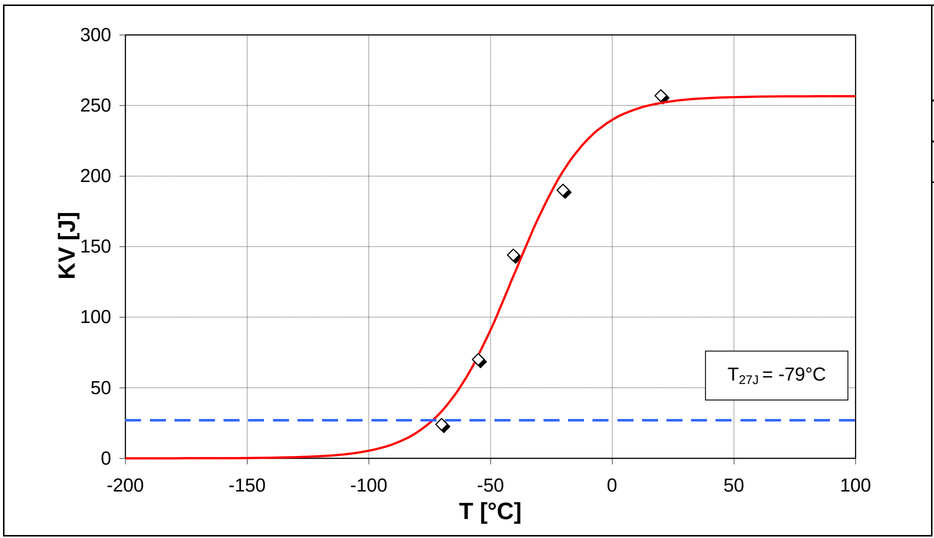
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
38	-78

RHS 180x180x12,5 – plane area, longitudinal direction



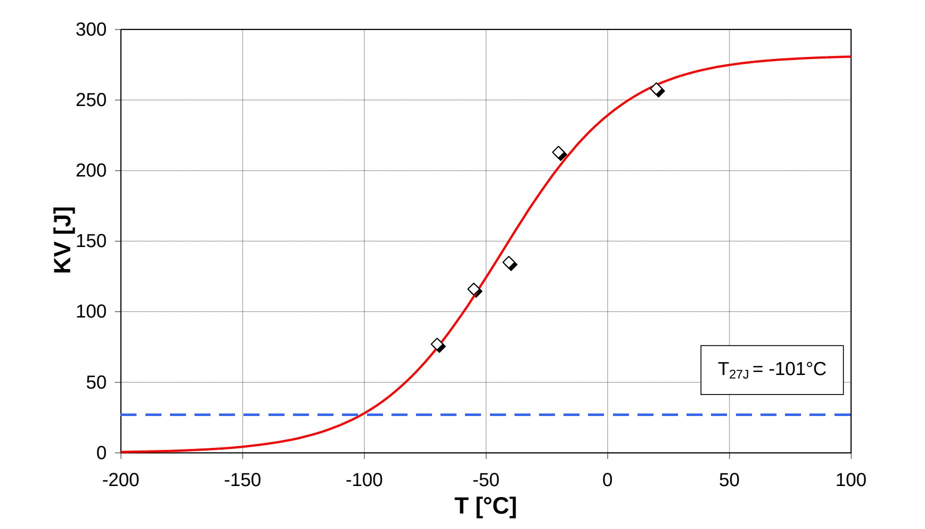
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
29	-72

RHS 180x180x12,5 – plane area, transversal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
24	-68

RHS 180x180x12,5 – corner area, inner notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 180x180x12,5 – corner area, outer notch

No.6 V&M D 16,0 - RHS 250x150x16,0 (S355J2H acc. to EN 10210)

Delivered as grade S355J2H from German supplier (V & M Tubes Düsseldorf).

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
250	150	16,0	24,0	16,0

Geometric dimensions of CVN-specimen

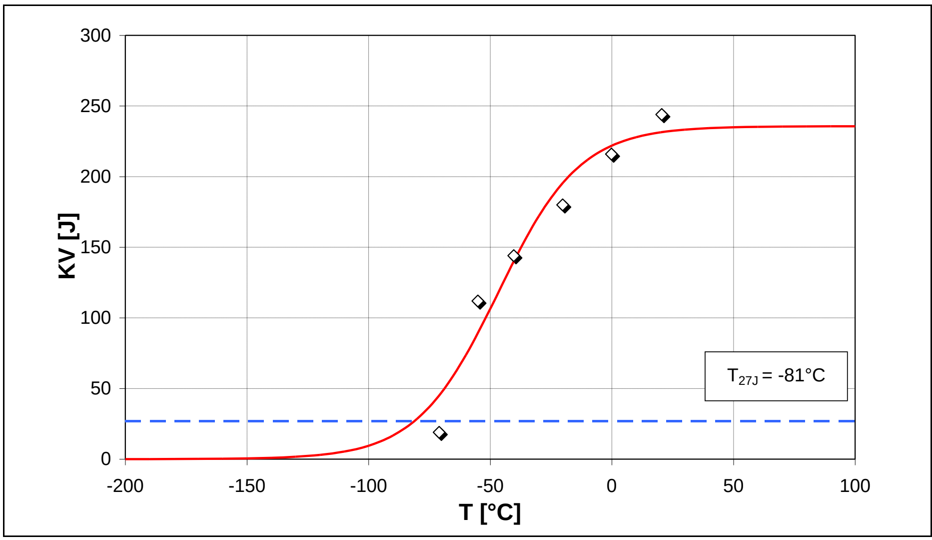
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	10	2	0,80	9,00

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,140	0,170	1,390	0,015	0,0010	0,002		0,037	0,050	0,010

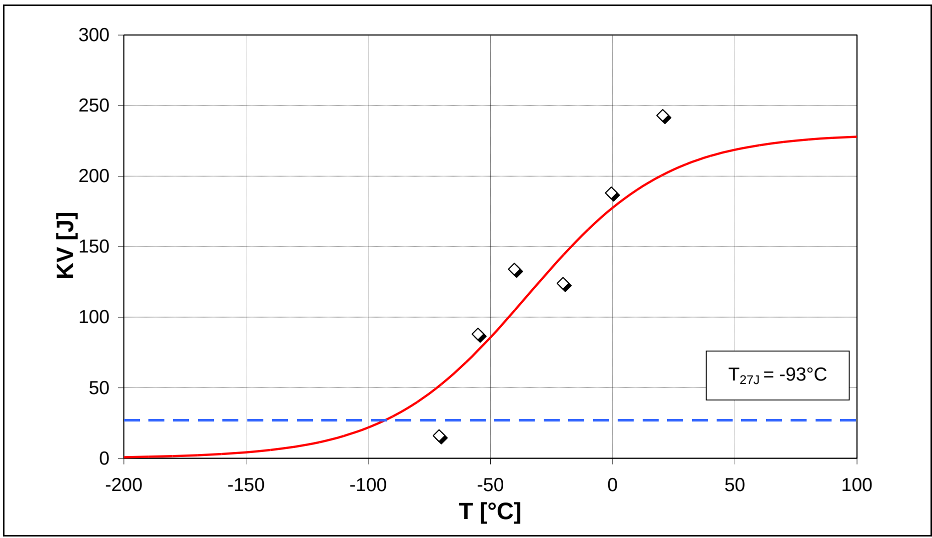
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,030	0,060	0,004	0,001		0,0003			0,0094			0,40

Impact energies



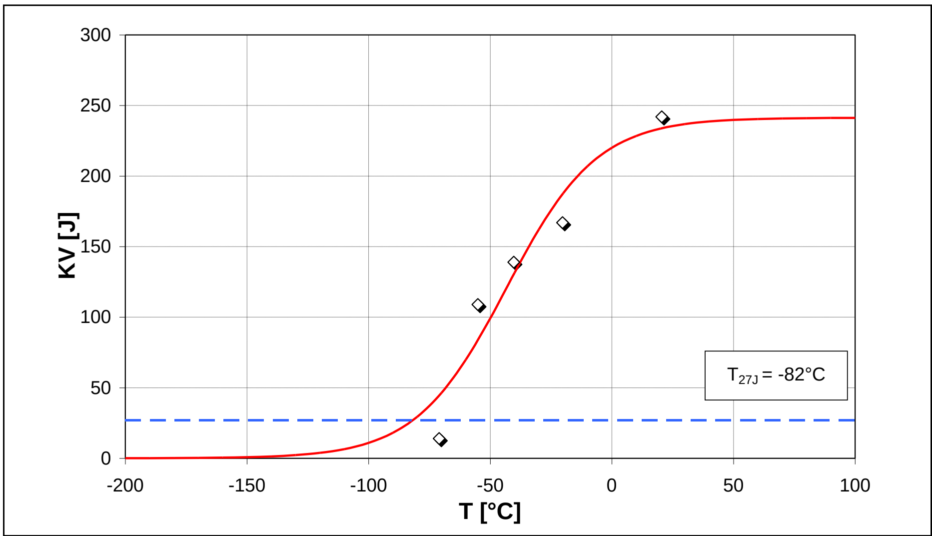
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
19	-64

RHS 250x150x16,0 – plane area, longitudinal direction



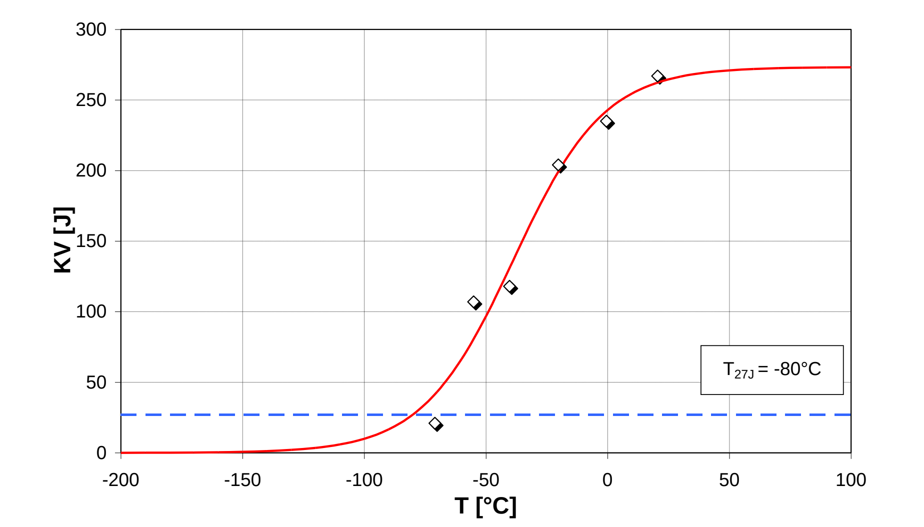
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
16	-61

RHS 250x150x16,0 – plane area, transversal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 250x150x16,0 – corner area, inner notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
21	-66

RHS 250x150x16,0 – corner area, outer notch

No.7 V&M D 17,5 - RHS 200x200x17,5 (S355J2H acc. to EN 10210)

Delivered as grade S355J2H from German supplier (V & M Tubes Düsseldorf).

Chemical analysis not available

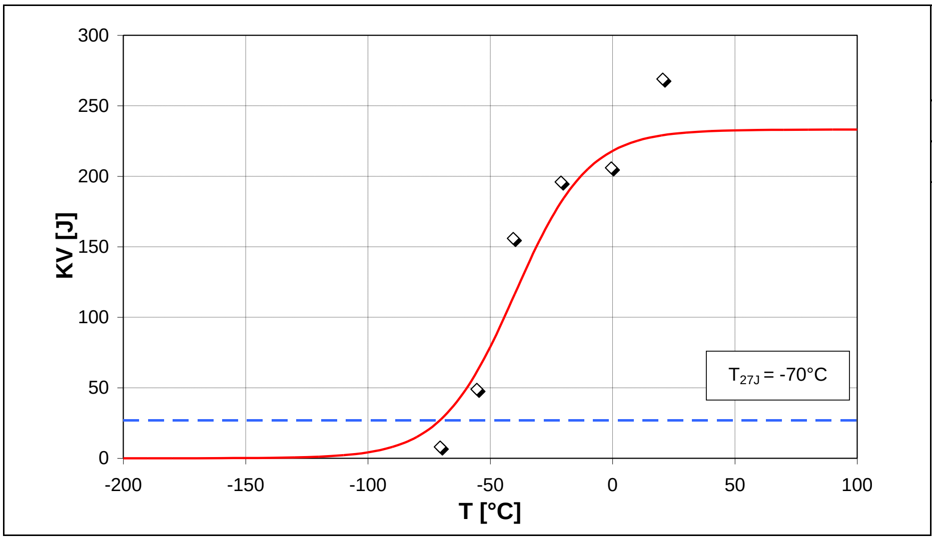
Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
200	200	17,5	26,25	17,5

Geometric dimensions of CVN-specimen

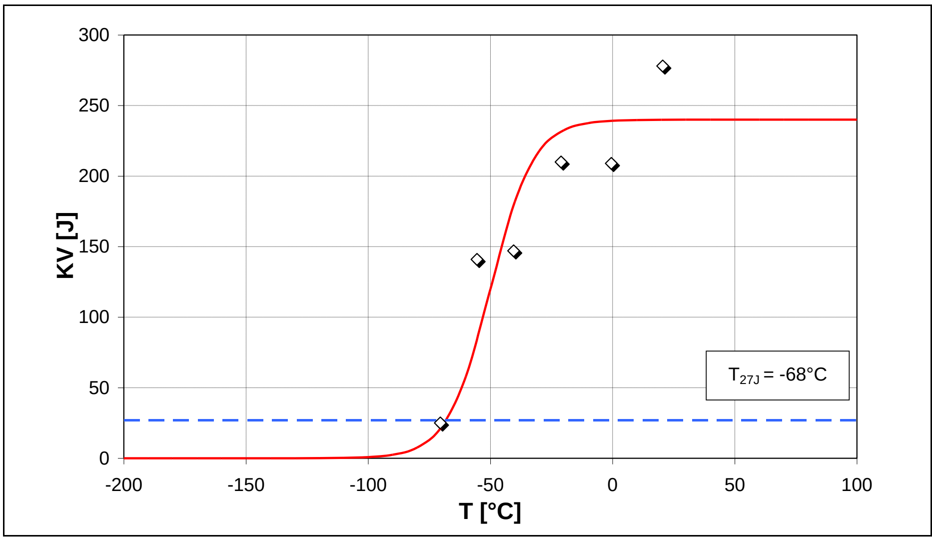
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	10	2	0,80	9,75

Impact energies



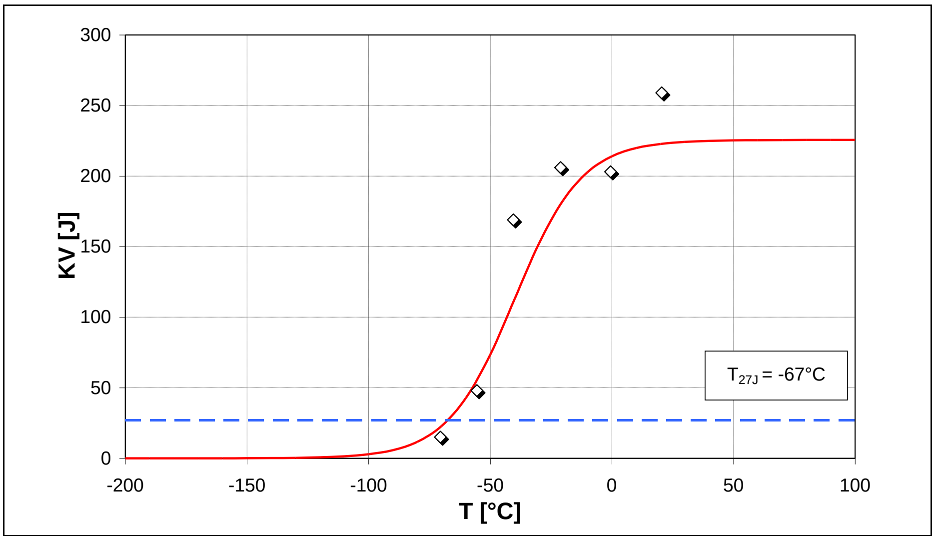
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
49	-70

RHS 200x200x17,5 – plane area, longitudinal direction



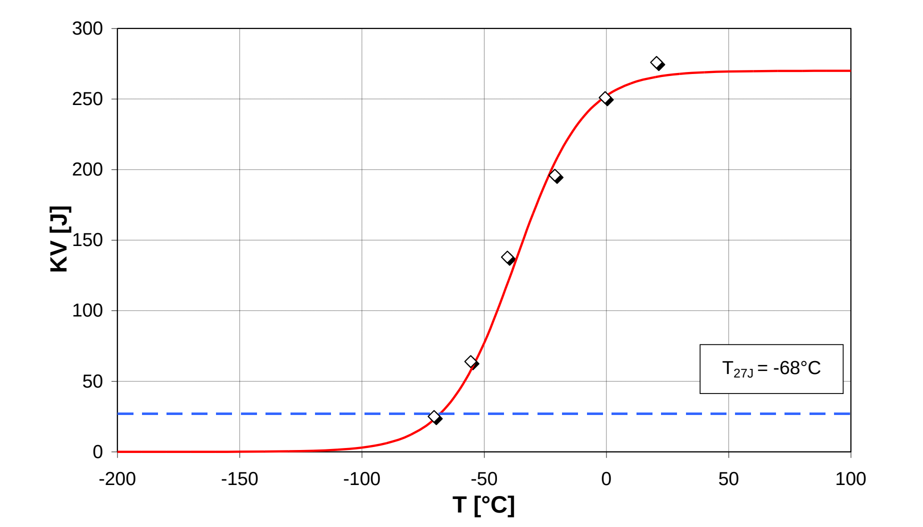
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
25	-69

RHS 200x200x17,5 – plane area, transversal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
48	-70

RHS 200x200x17,5 – corner area, inner notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
25	-69
64	-79

RHS 200x200x17,5 – corner area, outer notch

No.8 V&M D 20,0 - RHS 300x300x20,0 (S355J2H acc. to EN 10210)

Delivered as grade S355J2H from German supplier (V & M Tubes Düsseldorf).

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
300	300	20,0	30,0	20,0

Geometric dimensions of CVN-specimen

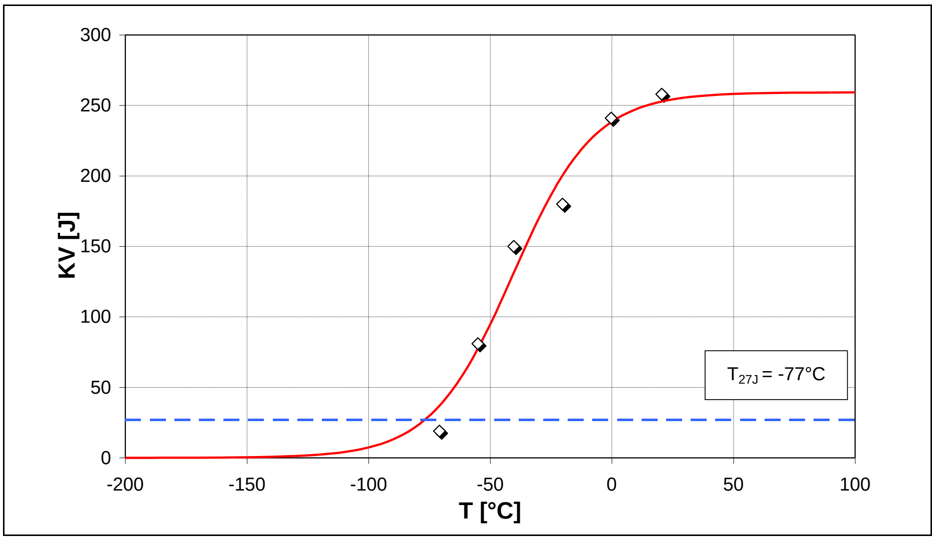
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	10	2	0,80	11,0

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,130	0,190	1,390	0,016	0,0009	0,040		0,025	0,060	0,020

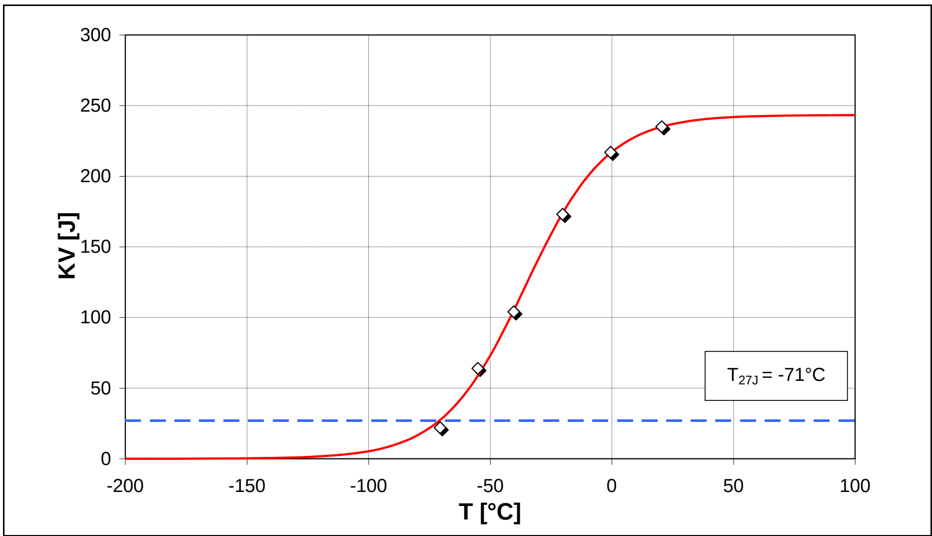
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,050	0,090	0,005	0,001		0,0003			0,0137			0,40

Impact energies



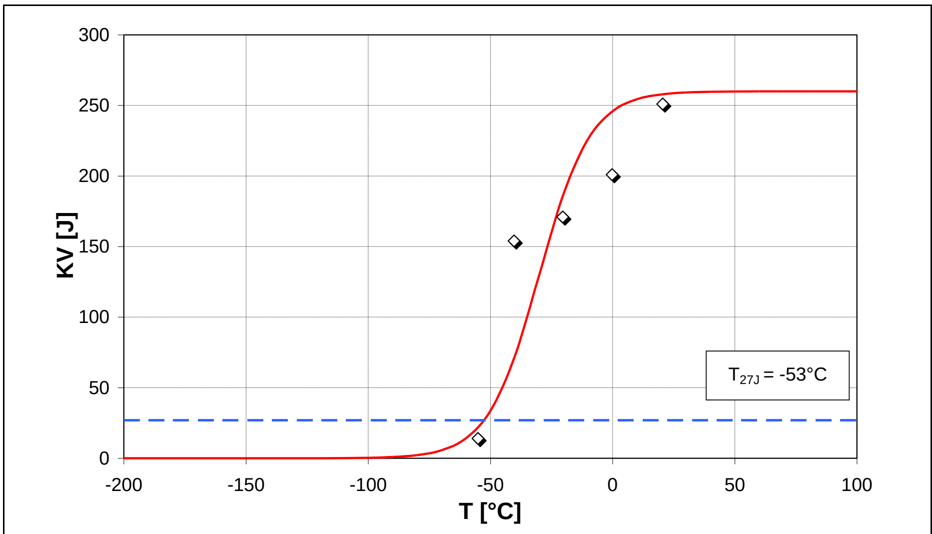
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
16	-64

RHS 300x300x20,0 – plane area, longitudinal direction



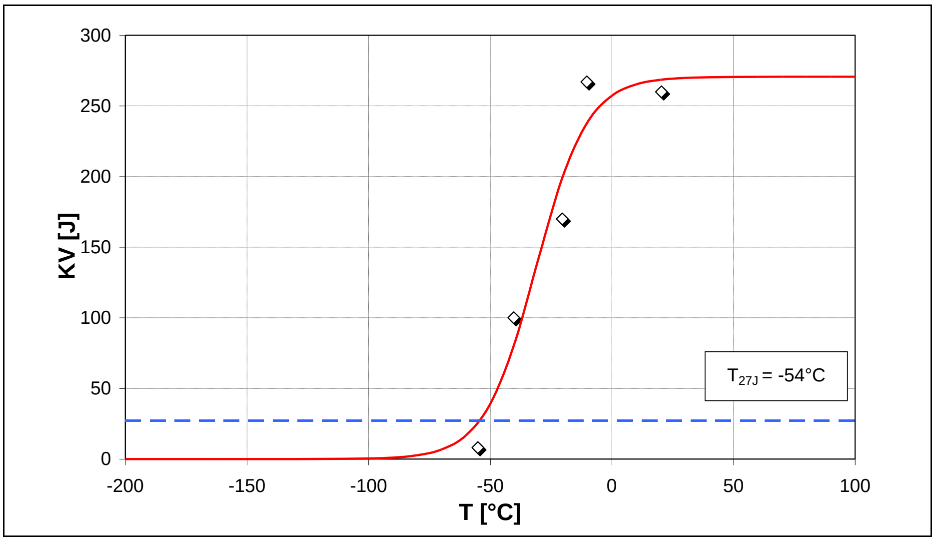
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
22	-66
64	-78

RHS 300x300x20,0 – plane area, transversal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 300x300x20,0 – corner area, inner notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 300x300x20,0 – corner area, outer notch

No.9 V&M Mh 11,0 - RHS 120x120x11,0 (S355J0H acc. to EN 10210)

Delivered as grade S355J0H from German supplier (V & M Tubes Mülheim).

Geometric dimensions of hollow section

b	h	t	r_a	r_i
[mm]	[mm]	[mm]	[mm]	[mm]
120	120	11,0	16,5	11,0

Geometric dimensions of CVN-specimen

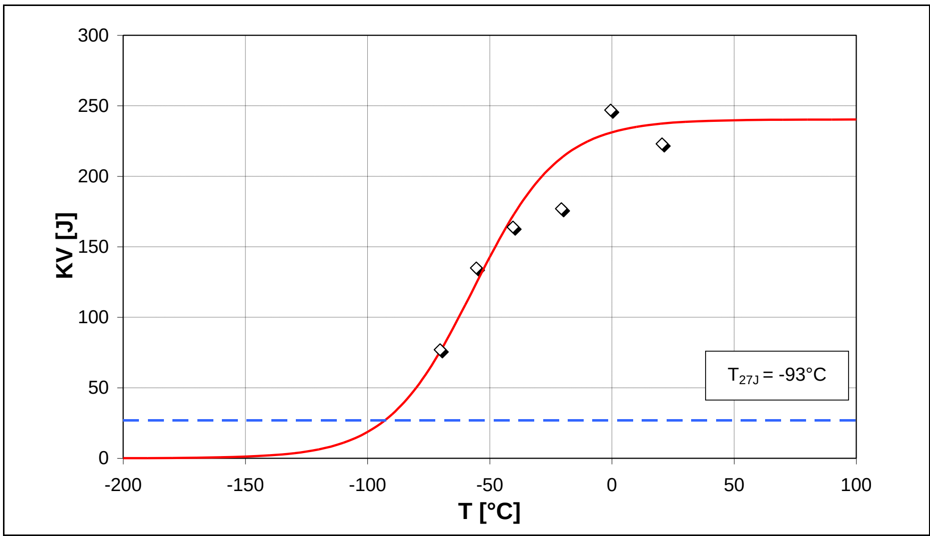
dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	10	2	0,80	6,50

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,17	0,18	1,35	0,012	0,0005	0,06		0,029	0,04	0,005

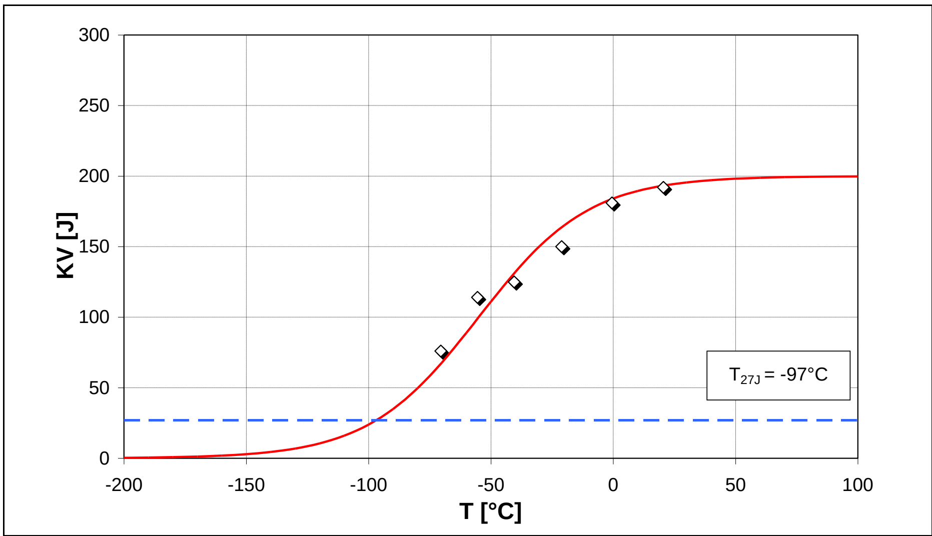
Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,03	0,045	0,0011	0,005	0,004	0,0004			0,0006			0,42

Impact energies



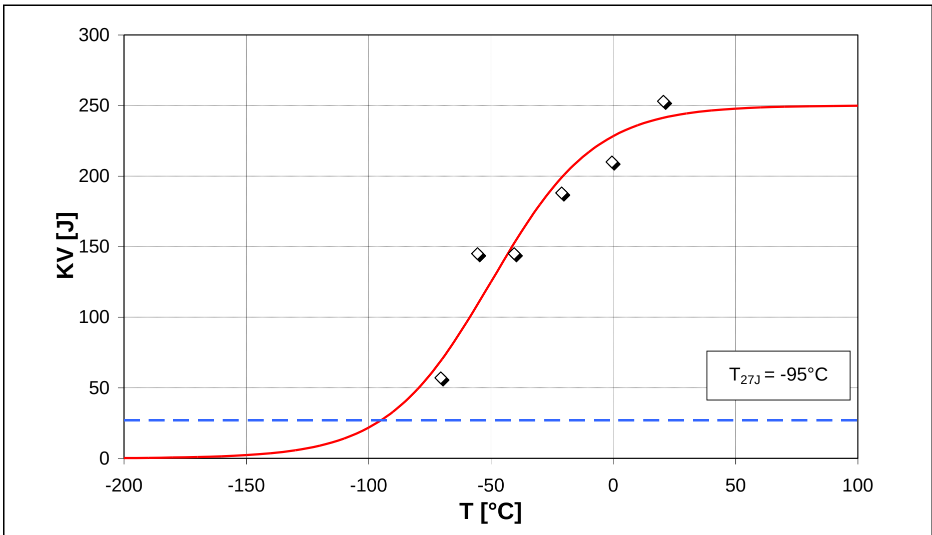
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 120x120x11,0 – plane area, longitudinal direction



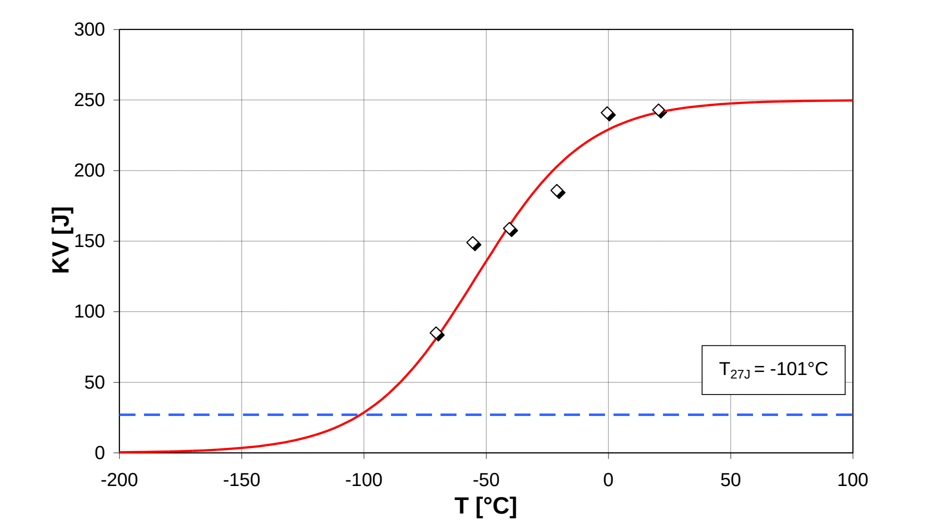
16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 120x120x11,0 – plane area, transversal direction



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
57	-90

RHS 120x120x11,0 – corner area, inner notch



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]

RHS 120x120x11,0 – corner area, outer notch

Annex A.4.3 Results from CIDECT 1B-report [15], circular sections

Sampling:

(1) Notch position was parallel to the surface as given in the following figures taken from the CIDECT 1B report.

No.10 1B-8 - CHS 324x8,4 (Steel equivalent to A53B, ASTM A53/A53M-01, hot-formed), Original tube

Delivered as grade A53B from Brazilian supplier.

Geometric dimensions of hollow section

D_a	D_i	t
[mm]	[mm]	[mm]
324	307,2	8,4

Geometric dimensions of CVN-specimen

dimensions			notch depth	notch area	position of CVN core area
l	w	h	c	A	z
[mm]	[mm]	[mm]	[mm]	[cm²]	[mm]
55	10	5	1	0,40	

Chemical analysis

C	Si	Mn	P	S	Cu	Sn	Al	Cr	Mo
0,100	0,210	0,960	0,013	0,004	0,000		0,024	0,020	0,020

Ni	V	Ti	Nb	Co	B	As	W	N	Zr		CEV
0,010	0,000										

Sampling according to Figure A4-3.

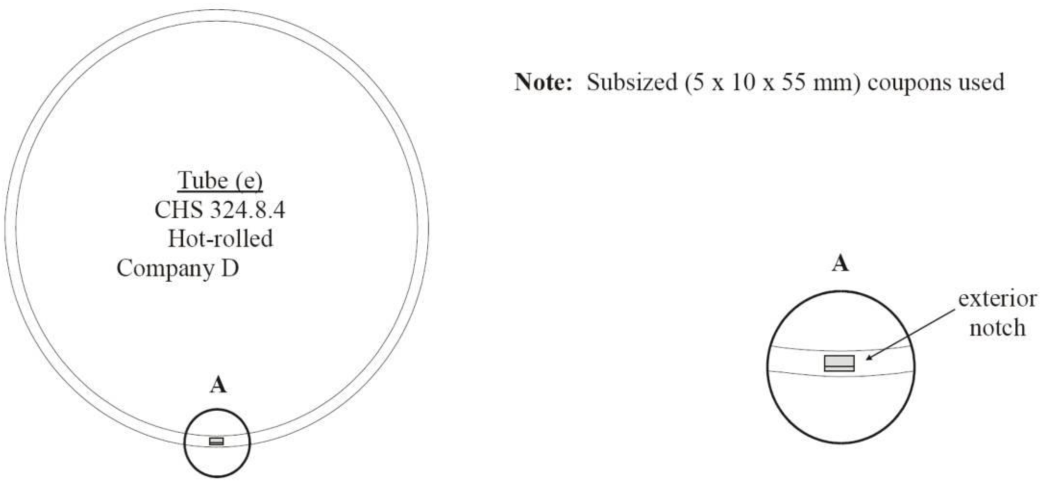
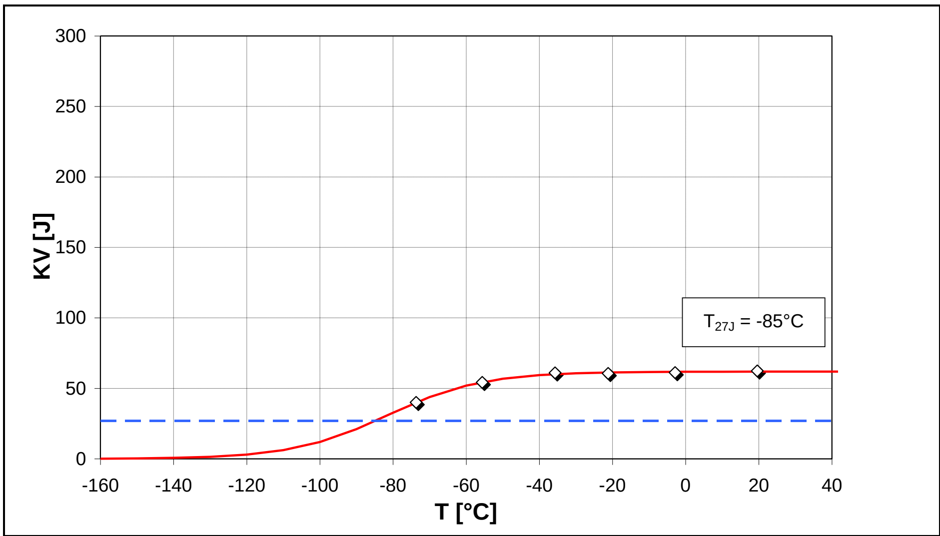


Figure A4-3: Position of Charpy-samples

Impact energies



16 J ≤ KV ≤ 67 J	
KV [J]	T_{27J} [°C]
40	-83
54	-74
61	-57
61	-43
61	-25
62	-3

CHS 324x8,4 – radius area, outer notch

LB-1A-25400-EN-N

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

Joint Research Centre

EU Science Hub

Publications Office

doi:10.2788/463273

ISBN 978-92-79-61761-4