



IQSim

USER MANUAL

DRAFT

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Introduction.

The idea.

The idea behind the IQSim project is that the teachers and students need to evaluate a set of parameters in order to find out which parameters are the most important to focus on, in a given context.

The IQSim tool is consequently a dynamic tool to be used in an evaluation process. It is not intended as being a tool for calculating a certain result only, but the tools should be used asking questions like: What happen if I select that parameter instead of another ?

IQSim is a tool for evaluation of consequences within the welding sector. That means we have been interested in asking: What happen if ...??. From a pedagogical point of view we want the students to make modifications and evaluate the consequences the results these modifications will give. This means we are not interested in the exact answer, but in the differences or relations that the modifications will give.

It is a tool developed through the project IQSim. This project is sponsored by the Leonardo pilot Project programme within the EU.

NOTE: This manual has been written for possible users of the program. However it is assumed that these user has the basic knowledge about welding. All welding terms and expressions herein is NOT explained. A non-welding person may therefore face difficulties with some of the expressions and the logic.

iQSim develops and disseminates a new generation of simulation services that will generate new training methodologies that are applicable to European wide mechanical industry sectors. The on-line simulator services that are interconnected to state-of-the art Computer Algebra Services (CAS) provide easy to use graphical interfaces that optimize cost- and time effective transfer of industrial production process and technology know-how to VET students. The combination of new pedagogical methodologies and simulator services, extend existing training methods.

Partnership:

The IQSim consortium has a strong industrial presence with strong ties to research within utilization of new pedagogical methodologies (HiST), development of simulator tools that utilise CAS tools (HCR and UTH), and connections towards mechanical industry (HiST, CFL, KU and MHE) for effective delivery of instructor training. HiST offers expertise in distance learning methodologies, blended learning, and visual communication and collaboration services.

For Teachers:

Please note that the IQSim tool can be operated on a Smartboard (Tm)(digital pressure sensitive board) together with the other Smartboard tools. The sliders and icons can then be operated tapping on the Smartboard surface.

A set of Teacher Use Cases have been developed in order to help the teacher formulating different questions to the students. This document can be obtained from the project organization.

System Requirements:

Web browser, preferably Firefox 3.5+, Internet Explorer 7+,

Adobe Flash 10+ plug-in **must** be installed

Project Lead Organization:

Sør-Trøndelag University College, Faculty of Technology , Norway

Participating organizations:

- HiST Contract Research, Norway
- Centrum för flexibelt lärande (CFL), Sweden
- Hungary Magyar Hegesztéstechnikai és Anyagvizsgálati Egyesülés (MhtE) , Hungarian Association of welding and Material testing , Hungary
- Klaipeda University, Faculty of Marine Technology , Lithuania
- University of Thessaly, Greece

Title:iQSim_A4.eps
Creator:GIMP PostScript file plugin V 1.
CreationDate:Tue Dec 15 08:08:58 2009
LanguageLevel:2

Start the system

You enter into the system through:

- Step 1. Log in with you user name
- Step 2. Enter your password, and the system will go to the introduction page for IQSIM.
- Step 3. Select which language to use within the system by clicking at the flag icon on the right hand side.



Fig 1. Select which language to use within the system by clicking at the flag icon on the right hand side, and that language will automatically be selected.

- Step 4. Select one of the system icons, or tabs, in the banner area to proceed with an action.



Fig 2. Select an action by clicking on one of the graphical icons or tabs in the border to proceed.

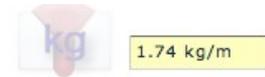
Please note that the IQSim system is designed for educational purposes. The key objective has been to develop a system with a simple and effective user interface which allows the students to evaluate the results and consequences of different decisions and learn them to see the fabrication process as a set of different actions which are influencing each other.

To get exact data may in some cases not be easy, but that has not been the intention of this user interface. However some different solutions for obtaining exact results has been implemented and you will be notified when these tools and facilities are available in the different parts of the system.

General user input.

| | |
|------------------------|--|
| To select a task | Click on the icon in the frame and the task will open. |
| To move a slider | Click on the slider pointer and press the left mouse button. Move the mouse button to the left or right and the pointer will follow. Note that a small information box appear above the pointer, highlighting its value. Or: Click on the slider at an arbitrary point with the left mouse button and the pointer will jump to the point selected at the slider. |
| Move a slider in steps | For selection of electrode or wire diameters. Click on the relevant diameter value and the pointer will move to that diameter. |
| Select an exact value | For chemical composition it is possible to enter exact values in the result box beside the slider instead of using the slider. |
| Activate/Deactivate | Click on the icon, yellow colour,  and it will deactivate some information and the icon will then turn white. Click on the white icon and it will be activated, together with its tasks and the icon get a yellow, active, colour. |

Calculated results from the simulation will be shown with yellow colour background, as an example:



However, in the welding calculations and the economic calculations other colour codes are used in addition for clarity purposes.

When you have selected the language, then you have to decide which evaluations and tasks you are going to carry out. By selecting one of the icons in the banner area you have different options either to carry out a single task or to carry on with multiple task simulations.

If you want to carry out simulations which involves multiple tasks, then you may freely move between the tasks in order to evaluate possible alterations on-the-fly. All datasets will be updated immediately.

NOTE: If you are using a Smartboard for communication with the system, then tap on an icon or select a slider pointer and drag it across the slider. The system is optimized for use with a Smartboard.

Different alternative simulations

You have the following options to select sequences and combine tasks:

Material composition.

Evaluate the consequences of alteration of the chemical compositions of the base material for CE, PCM values and so forth.
Select the following icon:

Title:fig-11.fig
Creator:fig2dev Version 3.2 Patchlevel 5
CreationDate:Mon Aug 10 19:37:04 2009
LanguageLevel:2

Material composition versus hardness and cooling rate

Evaluate the consequences of the chemical composition for the hardness value and cooling parameters.
Select the following icons in the sequence indicated below.

Title:fig-10.fig
Creator:fig2dev Version 3.2 Patchlevel 5
CreationDate:Mon Aug 10 19:36:14 2009
LanguageLevel:2

Geometrical properties.

Evaluate the consequences of altering the dimensions of a given joint configuration for weld metal requirements.
Select the following icons:

Title:fig-12.fig
Creator:fig2dev Version 3.2 Patchlevel 5
CreationDate:Mon Aug 10 19:40:56 2009
LanguageLevel:2

Geometrical properties versus welding costs.

Evaluate the consequences of altering the dimensions of a given joint configuration for welding

costs. Select the following icons in the sequence indicated below

Title:fig- ١٣ .fig
 Creator:fig ٢dev Version ٣.٢ Patchlevel ٥
 CreationDate:Mon Aug ٢٠٠٩ ١٩:٤٣:٤٤ ١.
 LanguageLevel: ٢

Welding parameters versus hardness and cooling time.

Evaluate the consequences of altering the welding parameters for the hardness and cooling.
 Select the following icons in the sequence indicated below.

Title:fig- ١٤ .fig
 Creator:fig ٢dev Version ٣.٢ Patchlevel ٥
 CreationDate:Mon Aug ٢٠٠٩ ١٩:٤٦:١٤ ١.
 LanguageLevel: ٢

Geometry and welding parameters versus welding costs.

Evaluate the consequences of altering the welding parameters for the welding costs.
 Select the following icons in the sequence indicated below.

Title:fig- ١٥ .fig
 Creator:fig ٢dev Version ٣.٢ Patchlevel ٥
 CreationDate:Mon Aug ٢٠٠٩ ١٩:٤٩:٢٨ ١.
 LanguageLevel: ٢

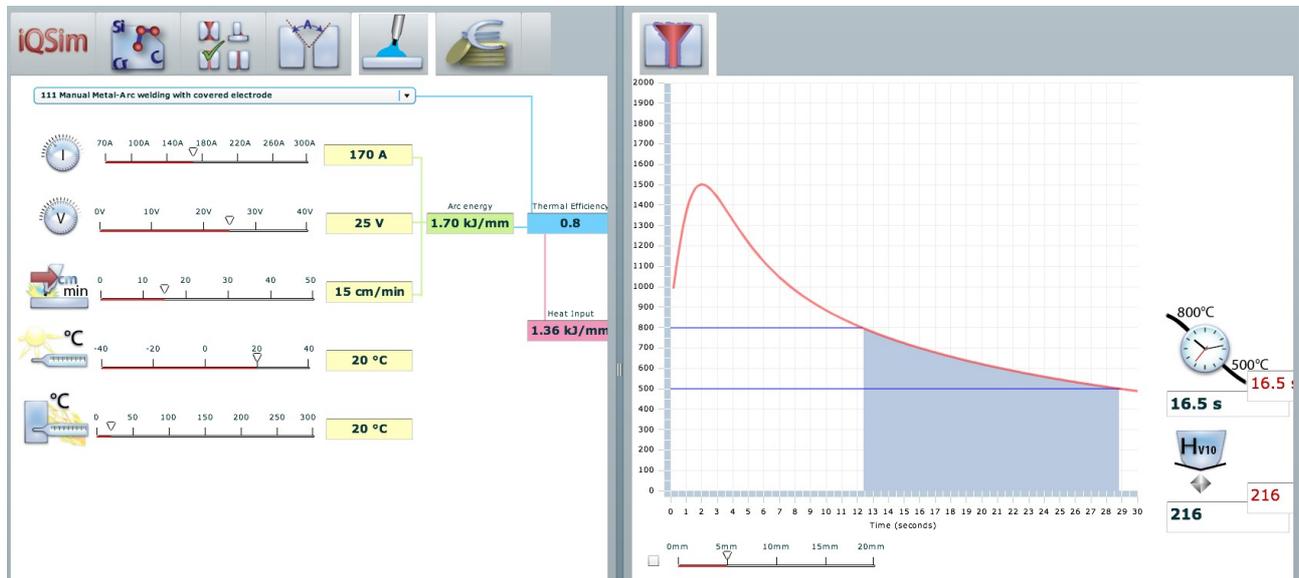
If you want to alter some of the previous settings, then move back to the icon were the settings are specified, carry out the alterations and move back again to the icon where you want to evaluate the consequences of the previous alteration.

You may also, during the simulation, decide to view two sessions or tasks, in parallel. That means you may select to see the influence of altering the welding details on the HAZ values and the temperature curve for cooling time.

To do this then drag ex. The HAZ icon into the canvas and scale it into the size you want to have. Each of the sessions may be scaled individually.

Later you may choose to put one of the icons back into the frame where the other icons resides in order to continue with one dataset only.

Evaluation and its consequences.



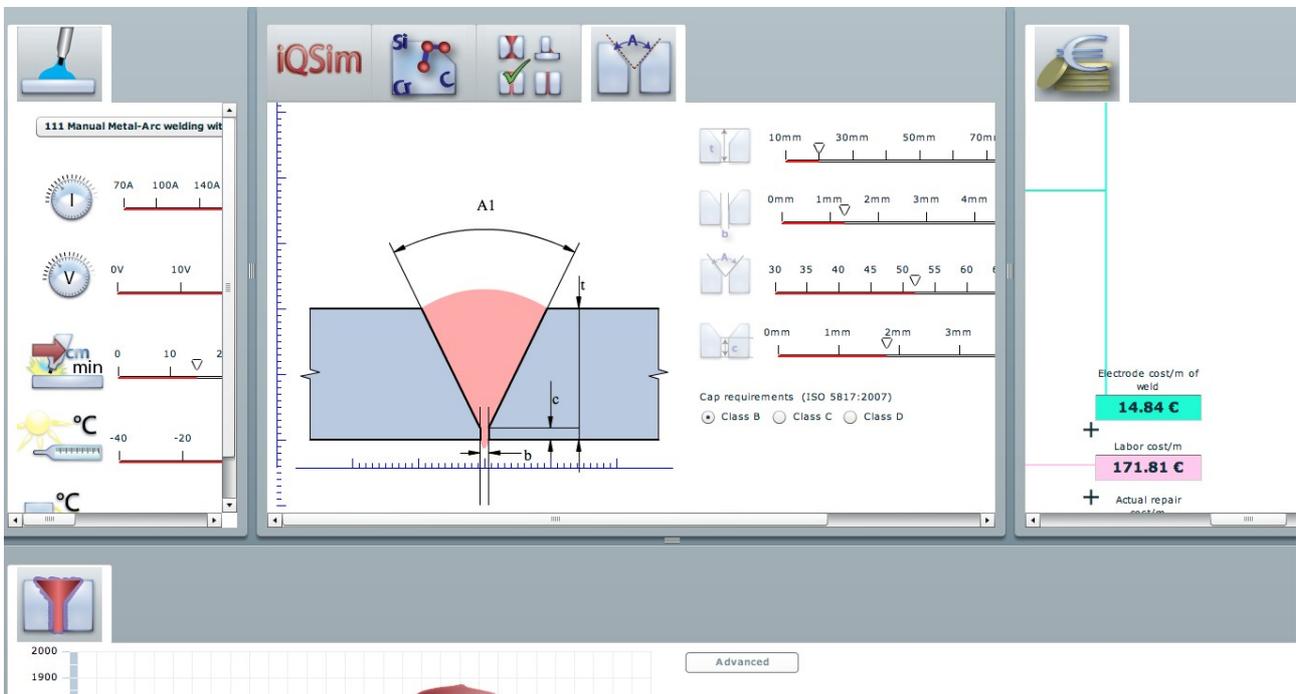
Example. The HAZ calculation graphs has been moved into the canvas and scaled so that the user can manipulate with the welding data in order to simultaneously monitor the result on the cooling time (and temperature curve) and Vickers hardness.

Similar comparisons, by showing the two items side by side, can effectively be made between the alterations of the geometry data and the cost data.

Moving the icons in the canvas

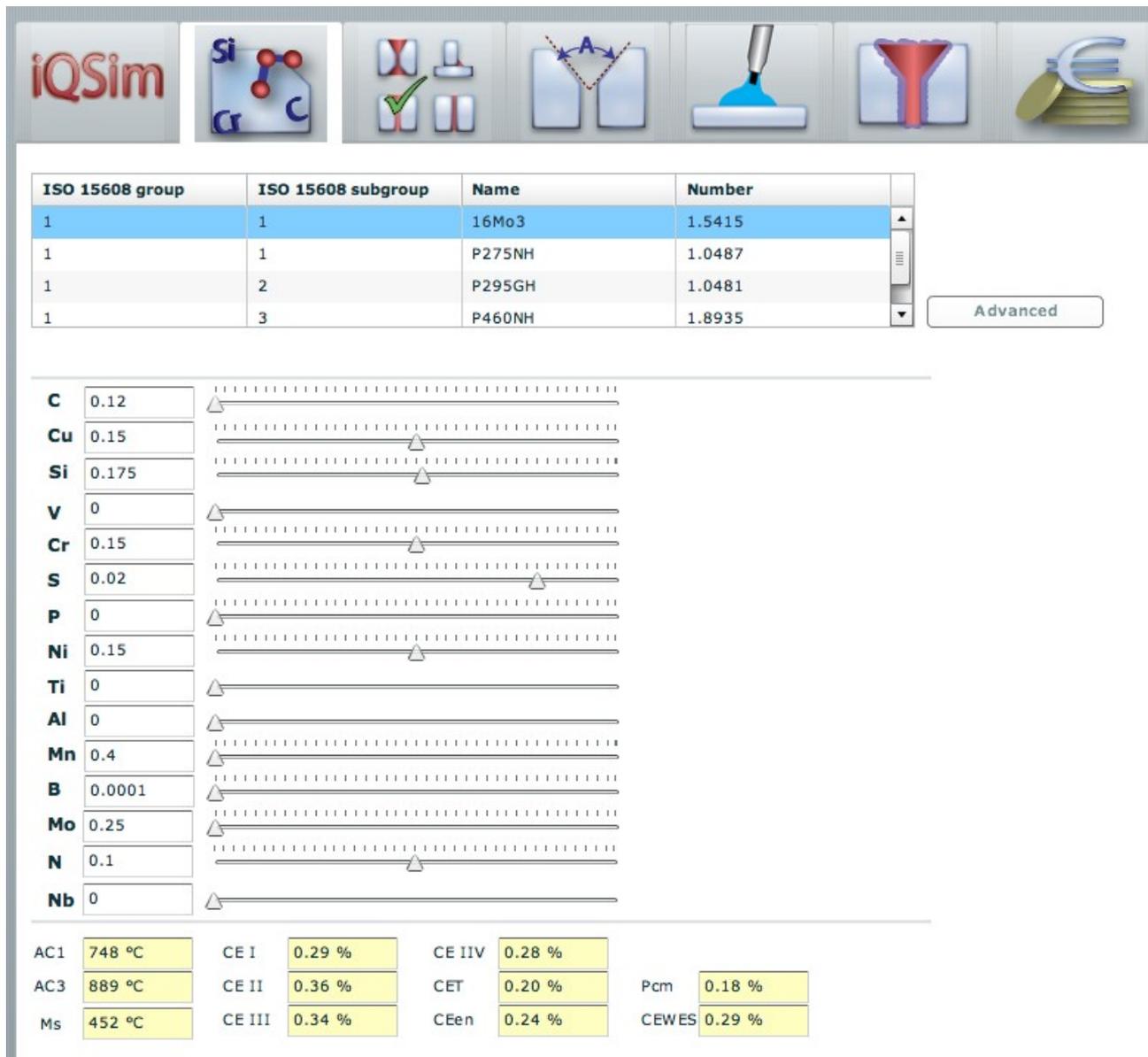
The icons can be moved around in the canvas if you select to do so. The canvas is divided into different segments, top and bottom segment, left and right segment and the centre segment. By dragging an icon into the segment, the segment will be circumscribed. Release the icon and it will then be moved.

Dragging the icon back into the top segment can be done. Drag the icon and move it in between the other icons and see that a box will be highlighted, then release the icon. The icon will then be inserted



Example of presenting results on the canvas.

Evaluation of the chemical composition



The interface displays a toolbar with icons for material selection, simulation, and cost calculation. Below the toolbar is a table of ISO 15608 materials, and a section for adjusting chemical composition parameters using sliders and input boxes. The result boxes for various parameters are highlighted in yellow.

| ISO 15608 group | ISO 15608 subgroup | Name | Number |
|-----------------|--------------------|--------|--------|
| 1 | 1 | 16Mo3 | 1.5415 |
| 1 | 1 | P275NH | 1.0487 |
| 1 | 2 | P295GH | 1.0481 |
| 1 | 3 | P460NH | 1.8935 |

Advanced

| | |
|-----------|--------|
| C | 0.12 |
| Cu | 0.15 |
| Si | 0.175 |
| V | 0 |
| Cr | 0.15 |
| S | 0.02 |
| P | 0 |
| Ni | 0.15 |
| Ti | 0 |
| Al | 0 |
| Mn | 0.4 |
| B | 0.0001 |
| Mo | 0.25 |
| N | 0.1 |
| Nb | 0 |

| | | | | | | | |
|-----|--------|--------|--------|--------|--------|-------|--------|
| AC1 | 748 °C | CE I | 0.29 % | CE IIV | 0.28 % | | |
| AC3 | 889 °C | CE II | 0.36 % | CET | 0.20 % | Pcm | 0.18 % |
| Ms | 452 °C | CE III | 0.34 % | CEen | 0.24 % | CEWES | 0.29 % |

In this window you have the following options:

1. You can select which material to use by scrolling and selecting from the menu.
2. You can use the sliders and move these back and forth in order to reach the value you want to have. The selected value will be shown in the value box on the left hand side of the slider
3. You can choose to insert the value itself in the value box and then use the slider to manipulate the value. This can be an interesting option if you need the value for a specific material data sheet or from a specific material charge.
4. By entering the data and use the sliders for data manipulation, the values in the yellow result boxes will dynamically be altered.

Grab the pointer on the slider by pointing at it and press the left mouse button down. Then move the mouse to the left or right side.

If the slider has no value in the value box on the left hand side and no marking or indications on the slider line, then this chemical composition is not valid for the material specified.

When you click at the pointer, then a small value icon will be shown above the pointer, highlighting the current value.

NOTE: A number of features are included in this window:

- If a comma has been typed into the value field, then it will be automatically be changed to a dot.
- The system will give an error sign, as a red border in the value box, if the value is not allowed, according the default value set as min or max value.
- If a chemical component is not defined in a material, then the slider for that component will not be active and it can not be moved.

NOTE: If the border in a value box turns red then the value selected is outside the permitted value in the ISO standard for that material group.

| | | | | | | |
|-----|--------|--------|--------|--------|--------|--------------|
| AC1 | 738 °C | CE I | 0.36 % | CE IIV | 0.35 % | |
| AC3 | 864 °C | CE II | 0.40 % | CET | 0.27 % | Pcm 0.22 % |
| Ms | 433 °C | CE III | 0.48 % | CEen | 0.34 % | CEWES 0.36 % |

Values which are calculated automatically in the material section are shown in yellow result boxes.

Values which will be altered dynamically during the simulation :

| | | |
|--------|--|---|
| | | |
| AC1 | The temperature at which austenite begins to be formed | |
| AC3 | The temperature at which the transformation of ferrite to austenite is completed. | |
| Ms | The temperature at which martensite formation begins during cooling of austenite. | |
| CE I | Carbon Equivalent (CE) for evaluation of the weldability of steel, according ISO 1011 | |
| CE II | Carbon Equivalent (CE) for evaluation of the weldability of steel, reference ISO 1011-but modified | Alternative algorithm defined by N.Yurioka. Corrections for chemical composition |
| CE III | Carbon Equivalent (CE) for evaluation of the weldability of steel, reference ISO 1011-but modified | Alternative algorithm defined by N.Yurioka. Corrections for chemical composition |
| CE IIW | Carbon Equivalent (CE) according IIW recommendations | This carbon equivalent satisfactorily evaluates weldability whose carbon content is higher than 0.12%. |
| CET | Carbon Equivalent (CE) for evaluation of the weldability of steel | Alternative algorithm defined by N.Yurioka. Corrections for chemical composition |
| CEen | | Susceptibility to cold cracking is determined by hardness of welds (HAZ and weld metal). The weld hardness is determined by an interactive effect of weld harden-ability and carbon content.. |

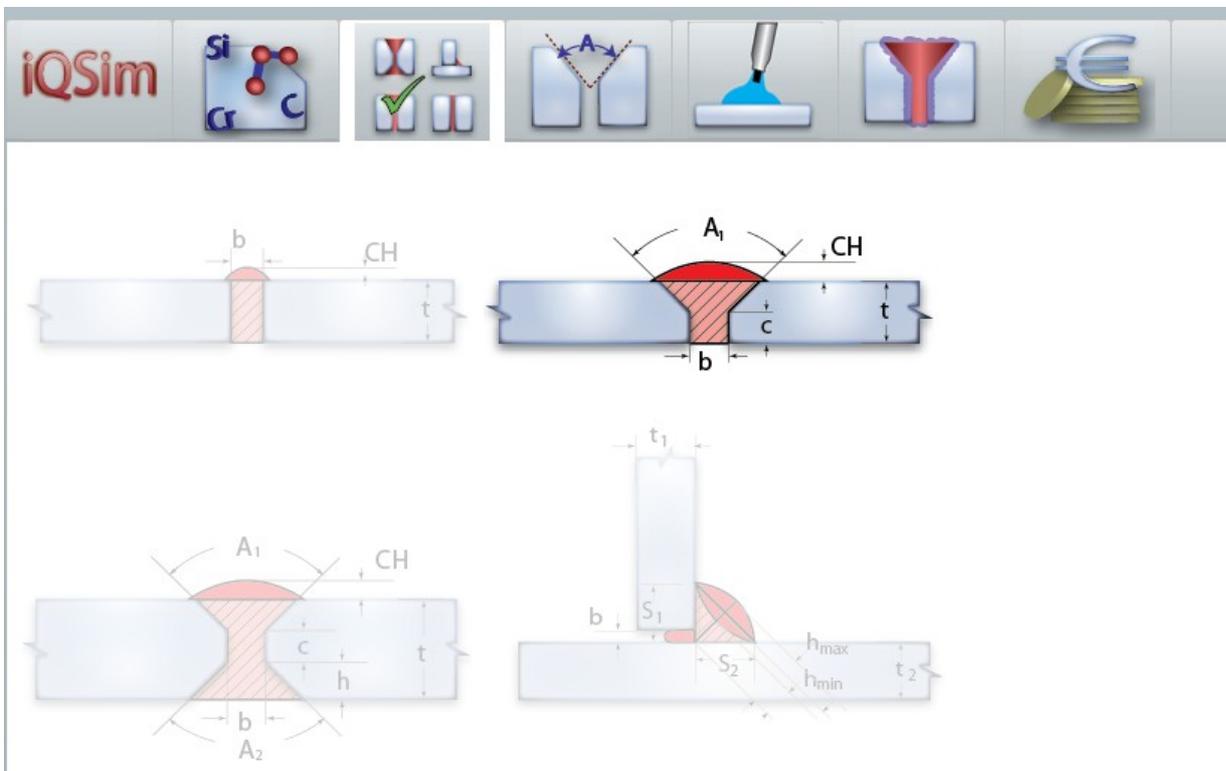
| | | |
|-------|---|--|
| | | The following carbon equivalent considers this effect and can evaluate weldability of steel with a wide range of carbon. |
| PCM | Parameter Crack Measurement, substitutes Ce values for carbon contents lower than 0.12% | Modern low alloy steel is mostly of a carbon reduced type ($C \leq 0.12\text{wt}\%$). Weldability of this type of steel is more adequately evaluated by the following carbon equivalent. |
| CEWES | Carbon Equivalent (CE) for evaluation of the weldability of steel | Alternative algorithm defined by N. Yurioka. Corrections for chemical composition |
| | Alternative algorithm defined by N. Yurioka. See: http://homepage3.nifty.com/yurioka/exp.html | |

For Formulas used for the calculations, see Appendix A

NOTE: All calculations are based on material ISO 15608, Group 1 ONLY. Other material group can not be added in the current version due to the use of algorithms optimized for this material group.

Evaluation of the weld geometry

The weld geometry may be evaluated in order to see the consequences of the alteration of the geometry dimensions for the welding itself. If you choose only to evaluate the geometrical changes then the result will be calculated as cross area section and weld requirements per meter weld. However you may select to combine this evaluation also with the cost evaluation in order to see the consequences of geometrical changes for the weld economy.



1. Select the icon for bevel configuration. The canvas will show the alternative joint configurations.
2. Click on the joint configuration you want to use. You may select one of the four configurations. The selected configuration will then be highlighted
3. Then select the icon for the weld bevel in the canvas and a new bevel interface will appear showing the evaluation parameters and the resulting data from the evaluation.

General input for the bevel data.

The screenshot displays the iQSim software interface for configuring bevel data. The top toolbar contains icons for the application, material selection (Si, C), joint types, bevel configuration, welding, and currency. The main workspace shows a 3D model of a bevel joint with parameters $A1$, t , b , and c . To the right of the model are four sliders for adjusting bevel angle, root face width, bevel angle, and root face width. Below the sliders are radio buttons for cap requirements (Class B, Class C, Class D) and a magnification icon. At the bottom, there are input fields for cross-sectional area (2.42 cm²), weight (1.90 kg/m), and maximum height (5.0 and 3.0).

Common for all bevel configurations are the following:

1. You may use the sliders to alter the geometrical data for the joint. By moving the sliders back and forth, the data will be altered dynamically
2. By selecting the relevant classes for cap requirements, Class B, Class C or Class D (according EN ISO 5617:2005) the maximum cap dimension will be included in the calculation of the cross section and the weld requirements in kg/m weld. Activate the button by clicking into it. The maximum cap height will also be calculated for the cap and root side.

Special features:

- * You may scale the drawing of the welded joint by clicking on the magnification glasses
- * You may switch the rulers ON/OFF by clicking at the ruler icon

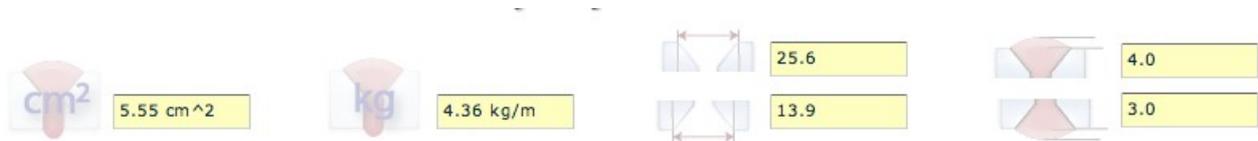
* You may switch the dimension lines ON/OFF by clicking on the dimension icon

At the bottom of the canvas you will get information about some of the key data; square area of the joint, required filler metal per meter weld. Main dimension of the joint, with in the top bevel and root width, maximum height of cap and root according the selected quality level according EN ISO 5617:2005.

Grab the pointer on the slider by pointing at it and press the left mouse button down. Then move the mouse to the left or right side.

When you click at the pointer, then a small value icon will be shown above the pointer, highlighting the current value, this value icon will follow the pointer and give you the correct pointer value in decimals.

Note: Some logical limitations are built into the system. Ex. Nose height can not be larger than the material thickness.



Values which are calculated automatically by the system are shown above and the values are shown with yellow background

BUTT WELD – I-Bevel

ISO 9692-1 recommendations (Single-sided weld/ Double-sided weld)

| | | | | |
|------------|----------------------------------|----------------------------------|----------------------------------|-----------------------------------|
| 111 | <input checked="" type="radio"/> | <input type="text" value="8.7"/> | <input checked="" type="radio"/> | <input type="text" value="4.35"/> |
| 141 | <input checked="" type="radio"/> | <input type="text" value="8.7"/> | <input checked="" type="radio"/> | <input type="text" value="4.35"/> |

Cap requirements (ISO 5817:2007)

Class B Class C Class D

Maximum height (ISO 5817:2007)

| | |
|-------------------------------------|-------------------------------------|
| <input type="text" value="5.9 mm"/> | <input type="text" value="2.4 mm"/> |
| <input type="text" value="5.9 mm"/> | <input type="text" value="5.0 mm"/> |

The use of the sliders and other manipulation tools are as described earlier in page 12.

NOTE. Recommendations according EN ISO 9692-1 for single- and double-sided welding has been added. Minimum and maximum plate thickness is highlighted for different welding methods.

BUTT WELD - V-Bevel

Cap requirements (ISO 5817:2007)

Class B Class C Class D

Maximum height (ISO 5817:2007)

| | |
|------|-----|
| 16.9 | 5.0 |
| 2.0 | 3.0 |

The use of the sliders and other manipulation tools are as described earlier in page 12.

NOTE The height of the cap on the cap and root side is given as well as the width of the top of the bevel.

BUTT WELD - X-Bevel

The use of the sliders and other manipulation tools are as described earlier in page 12.

NOTE: The sum of value c and value h can not be larger than material thickness. The with of the bevels are given as well as the cap height on the cap and root side.

FILLET WELD

Warning!! Fillet weld is not completely implemented
 Cap requirements (ISO 5817:2007)
 Class B Class C Class D

Maximum height (ISO 5817:2007)
 12.00mm 2.80mm

The use of the sliders and other manipulation tools are as described earlier in page 12.

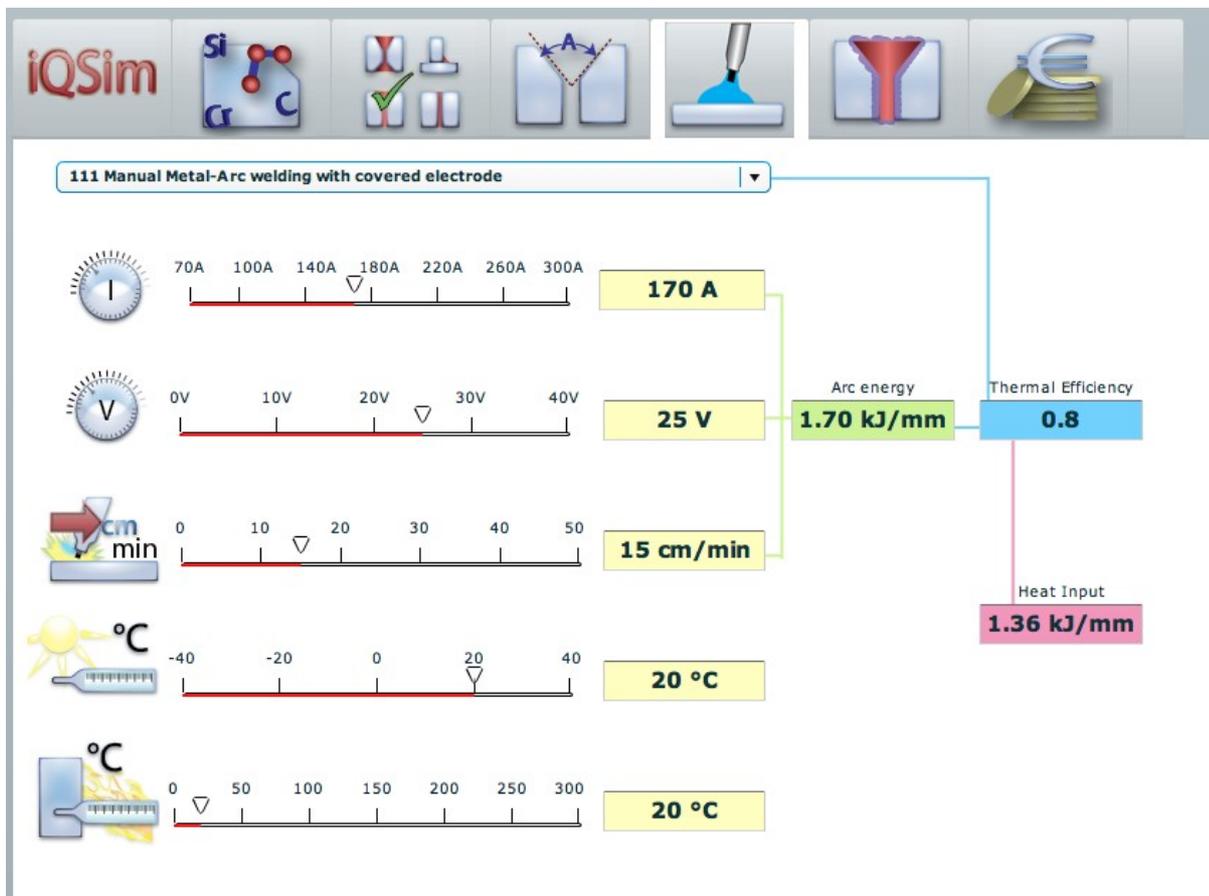
NOTE: The fillet weld can be set to be concave or convex by clicking at the icons. The selected icon will be highlighted.

Welding Parameters

The simulation of welding parameters has directly influence of the HAZ calculation and the cooling time. You may select to combine this simulation together with the HAZ calculation and the temperature cooling graph and calculation of cooling time. If so, it is advisable to drag the HAZ calculation into the canvas so that you will directly observe the consequences of your manipulation of the welding data into the HAZ data set.

Based on the variables in the user interface, the arc energy and heat input are shown as a result. You may manipulate with the following variables, by using the sliders, in this interface:

1. Amperage
2. Voltage
3. Welding speed
4. Ambient temperature
5. Preheat temperature
6. Welding process is selected through the pull down menu in the top of the user interface



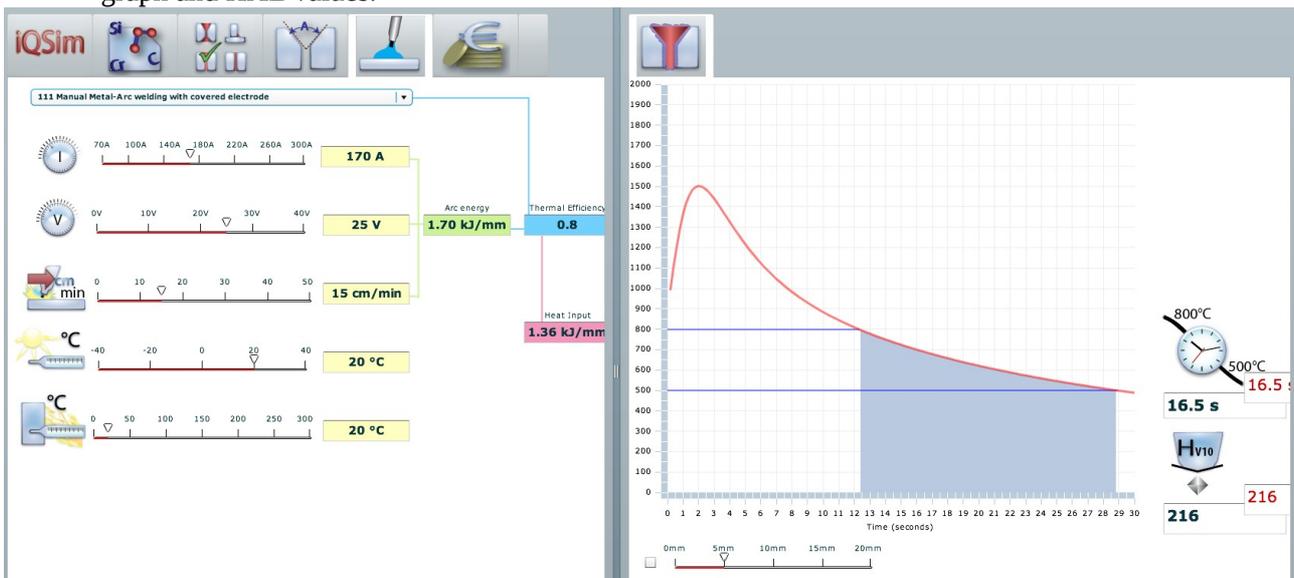
The selected values will be shown in the yellow result boxes on the right hand side of the sliders. The efficiency factor will be altered according the welding process you are choosing. Arc energy and heat input will be calculated automatically as you are manipulating with the sliders.

Note: Ambient temperature and preheat temperature do not influence the heat input calculation. Efficiency factor are dependent on the welding process and is set automatically. Ambient temperature is equal material temperature.

Welding parameters and HAZ/cooling time

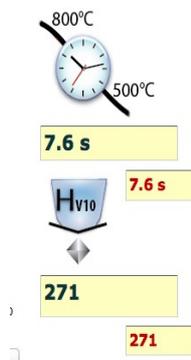
By manipulating the welding parameters this will directly influence the HAZ and the cooling time. In order to see this influence directly, you may do the following:

1. Enlarge the browser window
2. Move the HAZ icon into the canvas and the canvas will be divided in two parts
3. Scale these parts in proportions which suits you
4. When you now alter the welding parameters, these will directly be reflected in the cooling time graph and HAZ values.



This simulation has two extra features.

1. Click into the small slider box at the bottom of the graph. By doing so a new graph will be shown, illustrating the cooling curve in the selected distance in the material, from the HAZ itself. By using this function you will get a pretty good idea of the heat distribution into the material.
2. Both values for cooling time and Vickers hardness, HV10, have two values, shown in black and in red. The black value shows the result from the current simulation. The red value shows the results from the previous simulation.
3. By opening the two icons, for welding process and HAZ, you may differentiate the welding process, welding methods and welding parameters and at the same time see the result of the manipulation with the sliders directly in the graph.

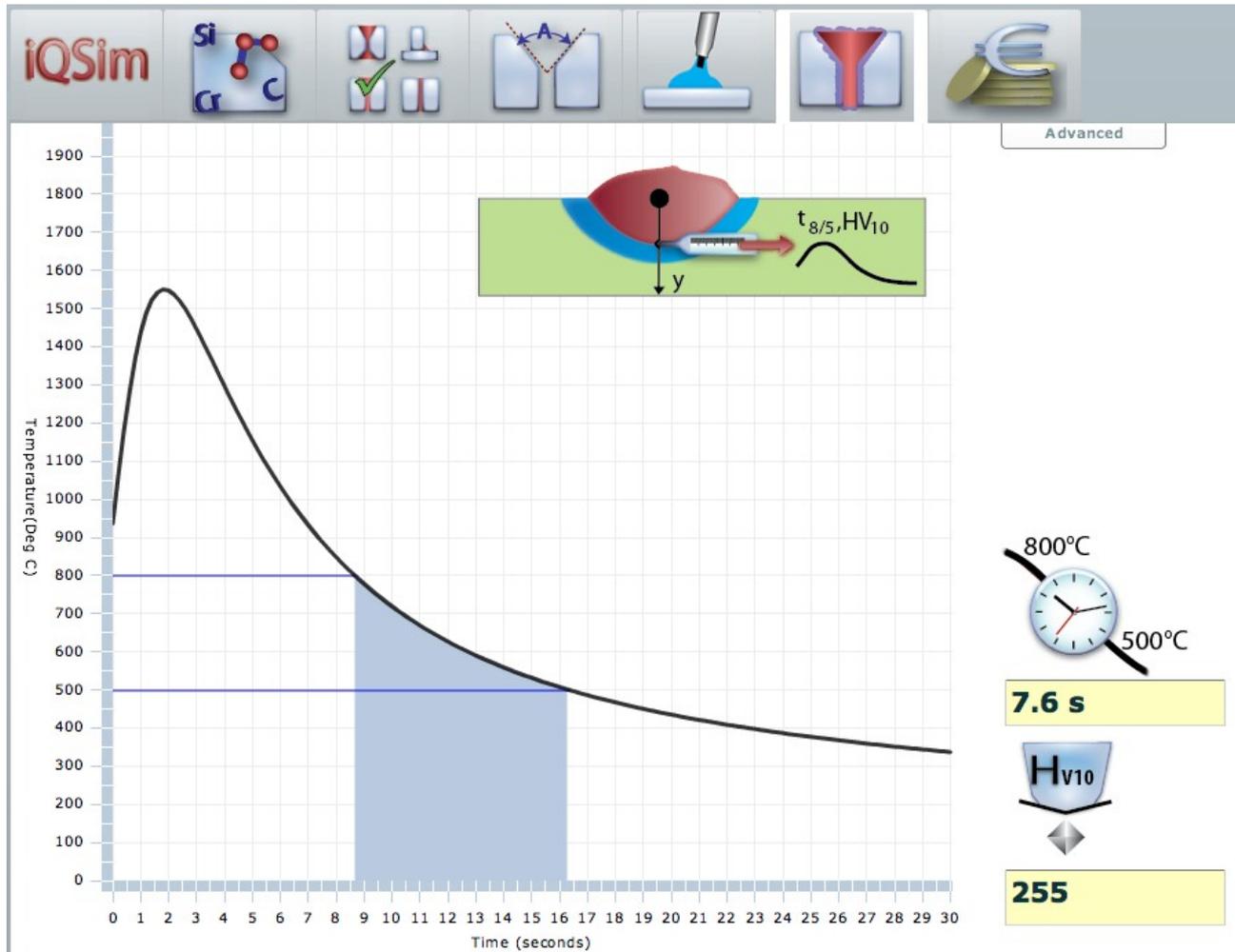


Red numbers give the result from the previous simulation. Black numbers are the result from the current one.

HAZ and cooling time.

The window for these calculations give you the following informations.

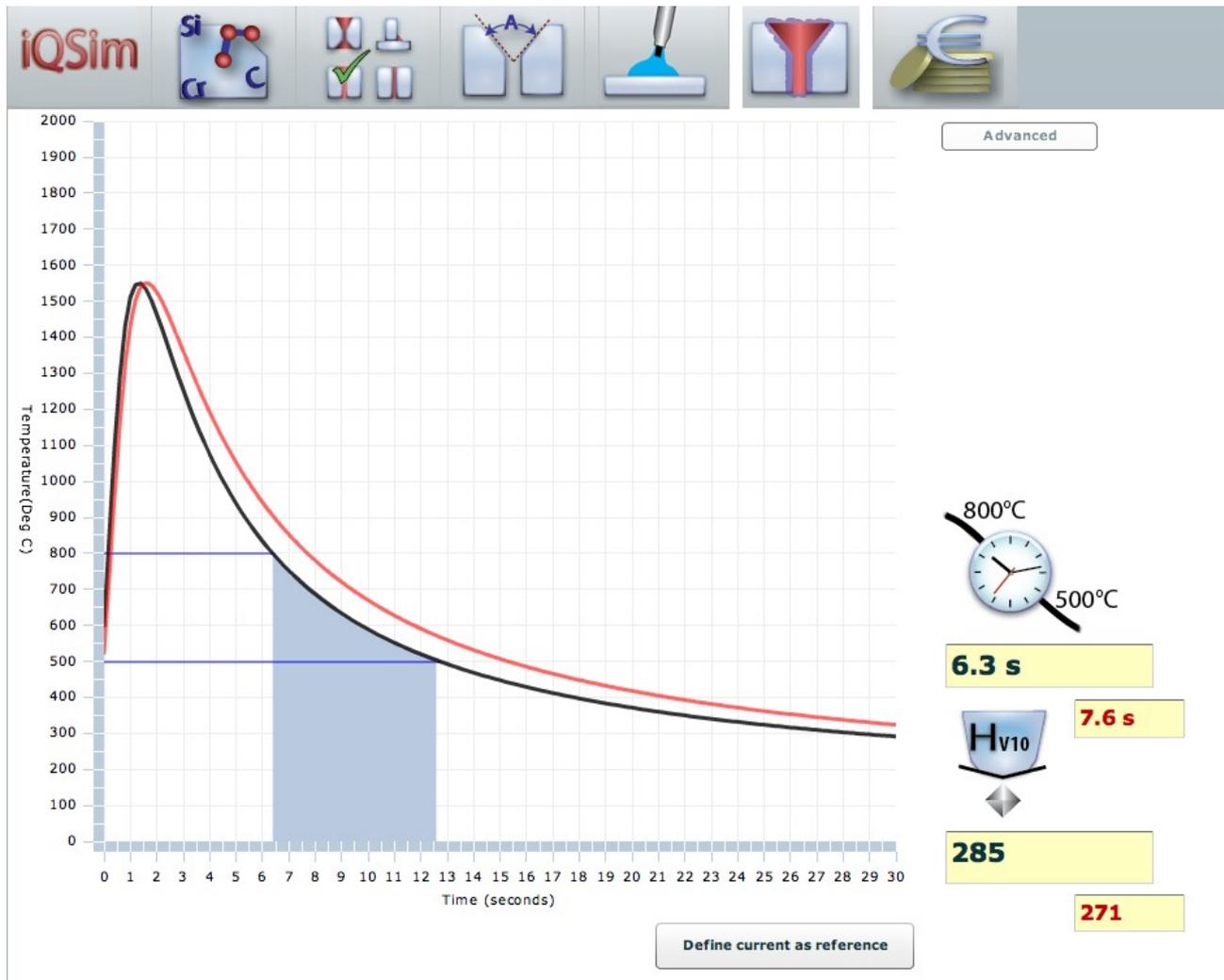
1. Maximum hardness (in HV10) in the heat affected zone.
2. Cooling time from 800 to 500 degree.
3. Cooling time in a given distance form the centre point in the weld itself.
4. Tensile strength
5. Hardness at given distances in the HAZ
6. Calculate width of the HAZ itself



By moving your cursor to the line at any arbitrary point will give you the temperature and cooling time for that very point.

Note that the values for HAZ and cooling time are shown in black and red. The black value, to the left, is the current value you get from this simulation. The red value, to the right, is the value obtained in the previous simulation.

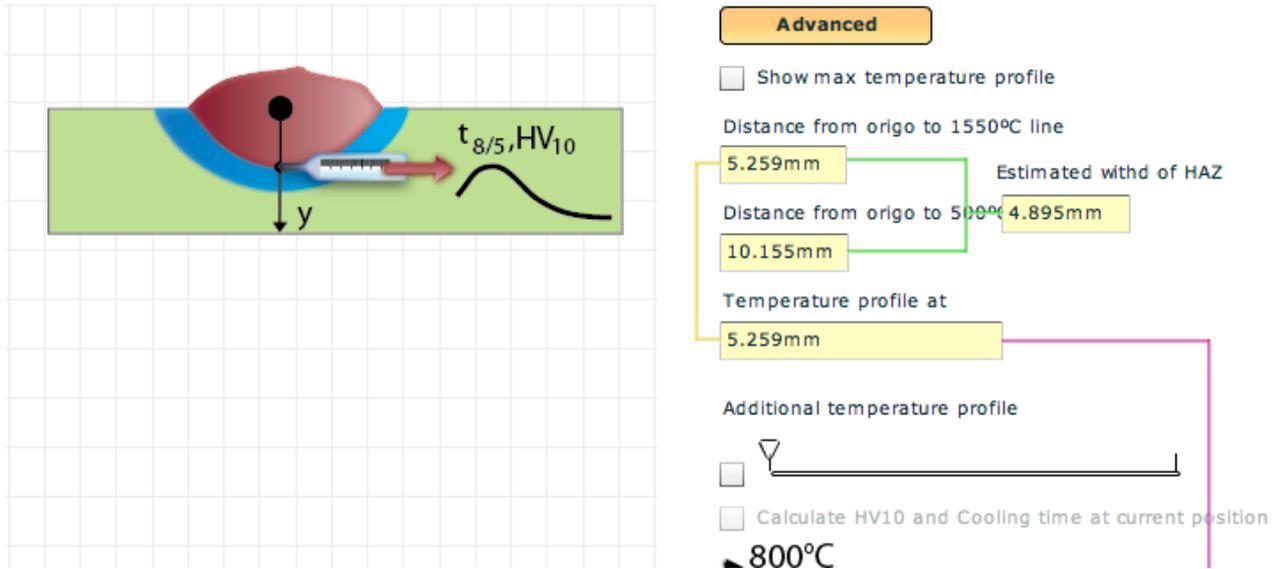
However--- the button: "Define current as reference" will both define the current curve and values as reference when you are carrying out the evaluation. Creating a new evaluation will then bring in a new cooling curve as well as new data for the cooling time and hardness. The previous curve, defined as reference, will be shown in red colour and the new one will be shown in black colour, as shown in the following figure.



NOTE: The accuracy of the calculations has to be verified by an appropriate test weld followed by a hardness test.

For the HAZ and cooling time calculation you have also two options. By ticking off in the selection box, available through the Advanced modus, you can choose to view the temperature development at a certain distance outside the HAZ region. Select the distance by using the slider. The result will be seen as a new graph, drawn in black. Or –you may select to see the maximum temperature profile through the weld by clicking into the selection box.

By using this graph, as shown below, you may get an additional information or indication on how the heat distribution will be in the material itself on each side of the HAZ region in a distance of approximately 12 mm. This indicates how wide the HAZ region will be.



The picture on the canvas indicates where the temperature and the HAZ is measured. If you click on the Advanced button, then additional information will be available and also additional possibilities will be available. The following information is calculated automatically:

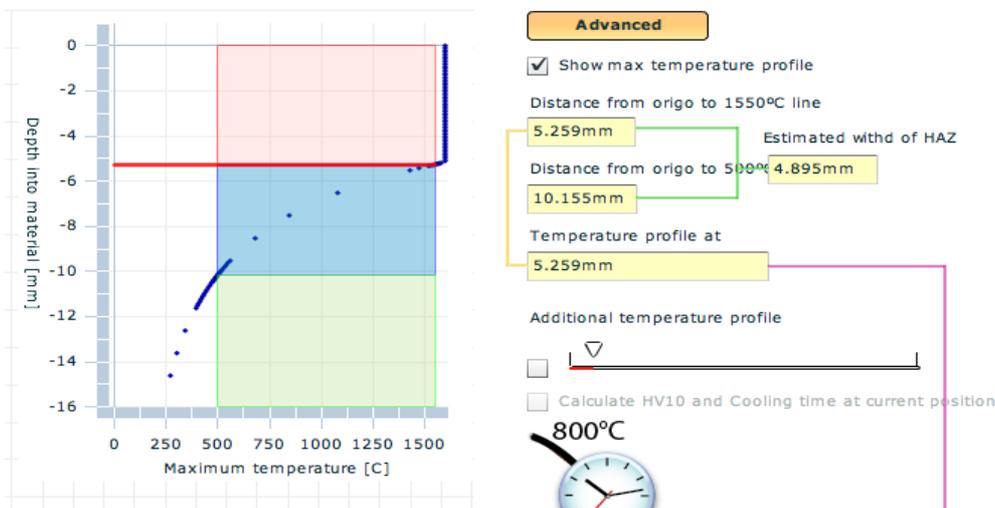
- Distance from origo to the 1550 C line.
- Distance from origo to the 500 C degree line.
- Estimated width of the HAZ

In addition you will get the following possibilities:

- Show max temperature profile
- Additional temperature profile

Show max temperature profile

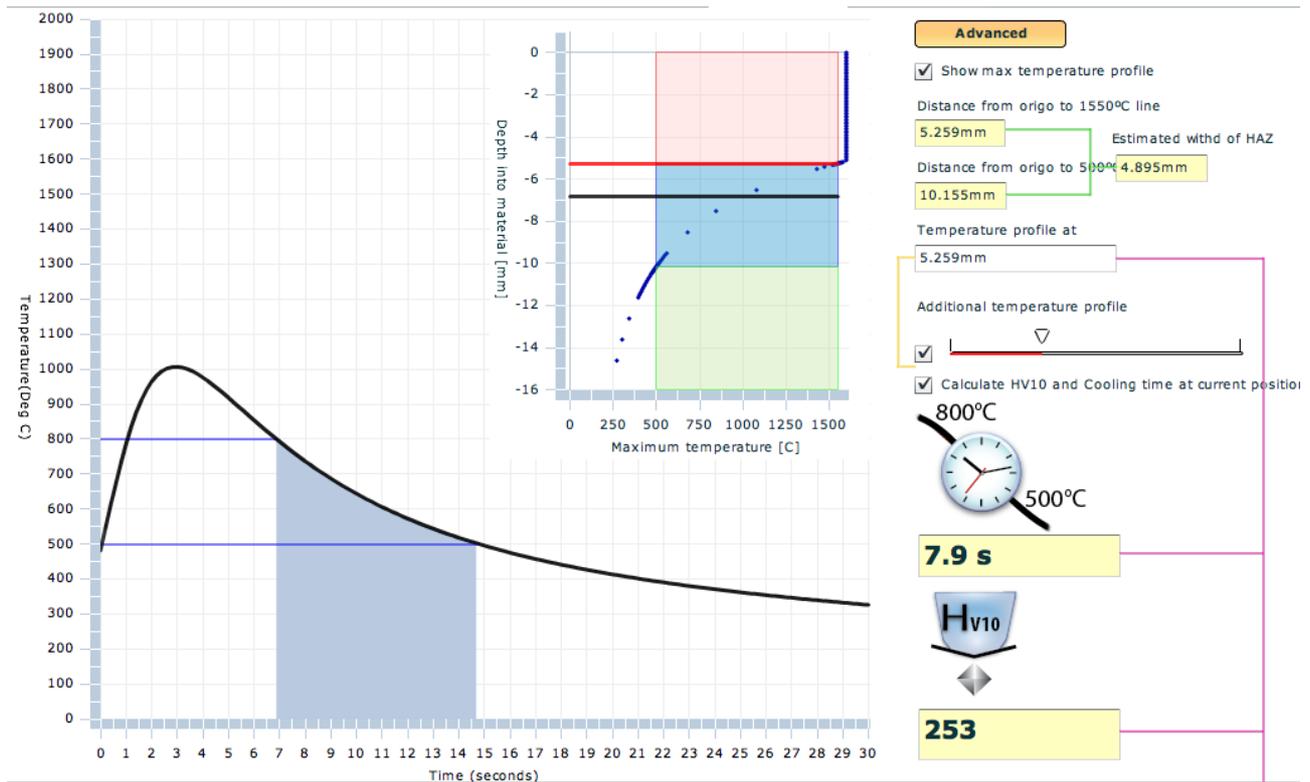
If you choose to tick off the box for selecting maximum temperature profile, then a graph will indicate the temperature profile vertical through the weld itself. The red vertical line illustrate the 1550 C line and the blue dotted line will be the temperature profile through the material.



Additional temperature profile

If additional temperature profile is selected, then the following will happen.

- A new graph will appear showing the temperature profile at the material depth as defined through the use of the slider. The selected value will also be shown in the dimension box above the slider.
- A new vertical black line will appear on the profile graph. This graph will give the temperature line for the material depth selected by the slider.



Note: If you also select the button: Use Current as Reference, then also a red reference curve as well as the red reference value boxes will be shown.

The tensile strength value will be shown below the Vickers hardness values.

The Advanced button thus allows you to evaluate the temperature and hardness values in the welded connection and get a feeling on how the distribution of values will be through the material and the weld itself.

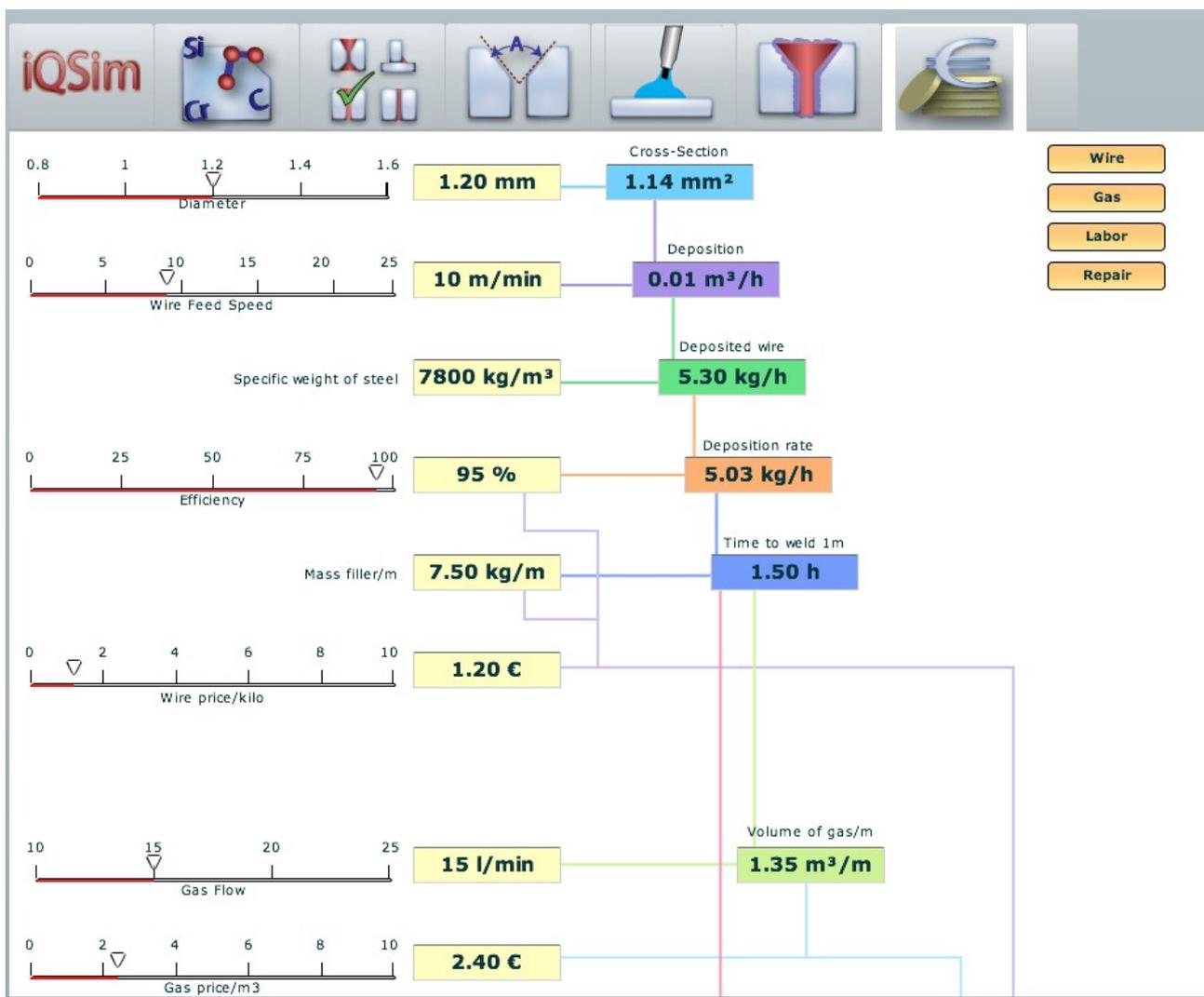
Economic evaluations

The economic evaluations are related to the joint configuration and import data from that part of the system. This means that you may select a joint configuration and then create an economic simulation, based on those data. You can then move back to the geometry of the joint and alter the data in moving back to the economy to see the result of the graphical alterations.

Also note that the welding process is defined behind the welding icon and when you alter the welding method, then the basic input in the economical calculation are altered. Ex from MMA -11 to TIG-141 the interface will alter electrode to wire and add cost elements for gas.

When you alter the geometrical data for the joint configuration, then this will influence the cost calculation.

User interface for economical simulation.



The user interface for the economical simulation follows the same path as for the other simulations.

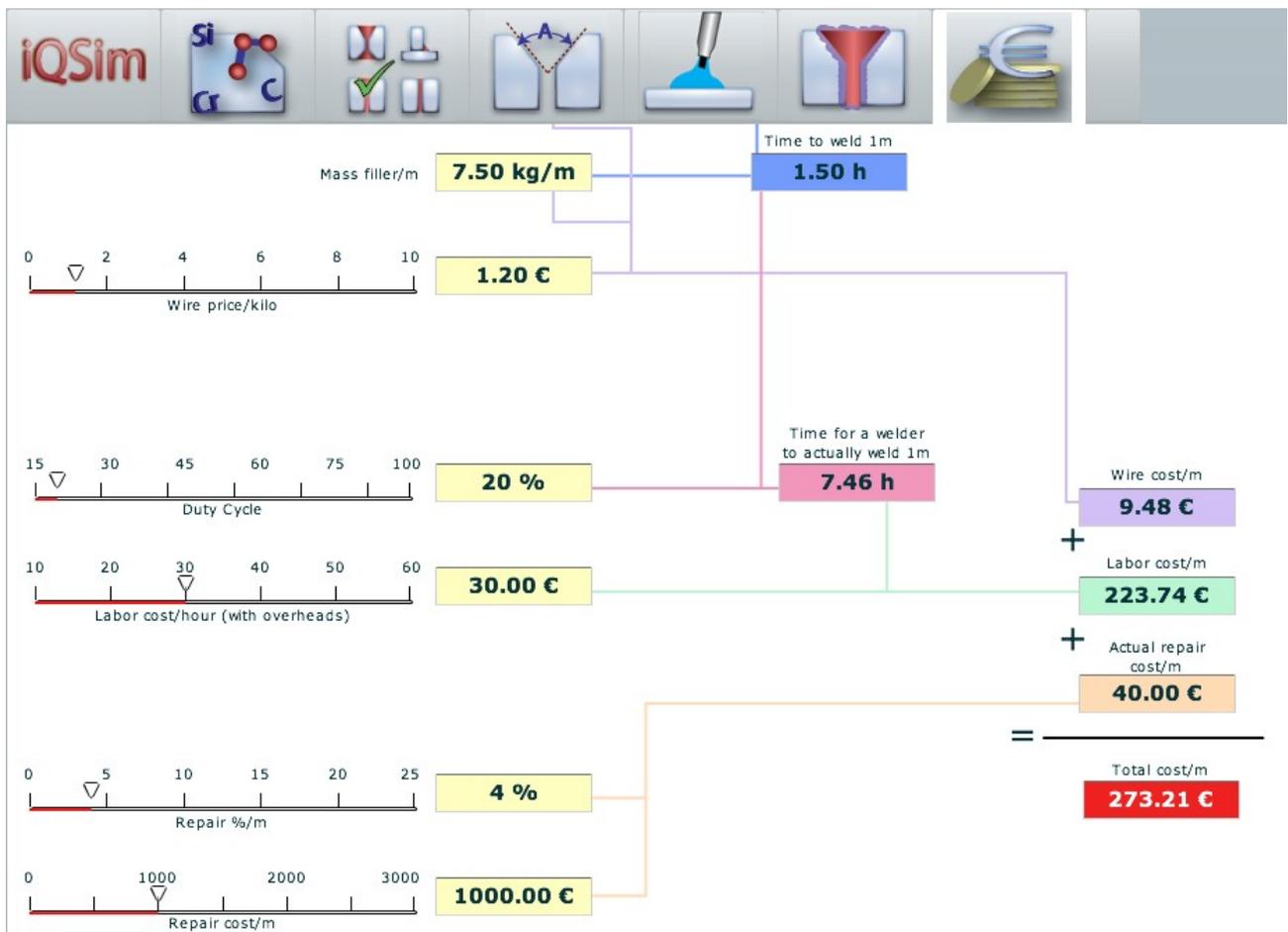
As you are moving the sliders, the resulting values are altered and shown in the yellow result boxes on the right hand side of the sliders.

However the resulting impact on the overall simulation and the total cost for the weld is then shown on the result boxes on the right hand side.

NOTE: A set of ON/OFF buttons are situated at the upper right corner of the canvas. The number of buttons will depend on the welding process. By clicking on one of these buttons you will hide the related cost elements away from the cost simulation. This will enable you to work within a smaller area of the overall calculation and concentrate on fewer variables, thus creating a smaller canvas area.

NOTE: For the wire or electrode diameter, the pointer will jump between the defined values of the slider. Just click at the slider value and the pointer will move.

NOTE: The total welding cost will be automatically updated if you go back into the geometry part and alter the geometrical information.



Data input:

Wire diameter

A set of predefined wire diameters are given in the slider. Click on the diameters and the slider will jump to the selected diameter. Only the predefined values can be used.

Wire feed speed

Select the wire feed speed according your requirements. The selected value will also be seen in the value box on the right hand side. The speed is defined as meter per minutes.

Efficiency

Efficiency factor for the wire, taking into consideration possible losses in

| | |
|------------------------------|--|
| | weight from wire to weld metal |
| Wire price/kg | Price in Euro per kilo for the wire. |
| Gas flow | In litre per minute. |
| Gas price/m ³ | Price in Euro per cubic meter of gas. |
| Electrode diameter | A set of predefined electrode diameters are given in the slider. Click on the diameters and the slider will jump to the selected diameter. Only the predefined values can be used. |
| Kilo weld metal/kg electrode | Select the deposit value for the electrode. |
| Deposition rate | Deposition rate for the selected electrode per hour. |
| Welding speed | Welding speed in centimetre per minutes |
| Duty cycle | Duty cycle or arc time, in %, for the welding process. This means effective welding % per hour. |
| Labour costs/hour | Labour cost per hour. Note: It is wise to use the total price here. That means the company costs and overhead should be added. Or one may use the company sales price per hour. |
| Repair % | Repair % per meter weld. Average number to be used. |
| Repair costs/meter | Repair costs per meter should at least include the following elements: <ul style="list-style-type: none">• Cost for gauging and grinding in order to remove the weldment,• Costs for re-weld,• Costs for renewed control and documentation.• Additional cost for handling equipment back and forth for control and welding purposes should also be included.• Cost for documentation of the repair |

Administration of material data

| ISO 15608 group | ISO 15608 subgroup | Name | Number |
|-----------------|--------------------|--------|--------|
| 1 | 1 | 16Mo3 | 1.5415 |
| 1 | 1 | P275NH | 1.0487 |
| 1 | 2 | P295GH | 1.0481 |
| 1 | 3 | P460NH | 1.8935 |

Advanced

| | | | Min | Max | Slider stepping |
|-----------|--------|--|------|--------|-----------------|
| C | 0.12 | | 0.12 | 0.2 | 0.00200000 |
| Cu | 0.15 | | 0 | 0.3 | 0.0075 |
| Si | 0.175 | | 0 | 0.35 | 0.00874999 |
| V | 0 | | 0 | 0 | 0 |
| Cr | 0.15 | | 0 | 0.3 | 0.0075 |
| S | 0.03 | | 0 | 0.025 | 0.000625 |
| P | 0 | | 0 | 0.03 | 0.00075 |
| Ni | 0.15 | | 0 | 0.3 | 0.0075 |
| Ti | 0 | | 0 | 0 | 0 |
| Al | 0 | | 0 | 0 | 0 |
| Mn | 0.4 | | 0.4 | 0.9 | 0.0125 |
| B | 0.0001 | | 0 | 0.0001 | 0.000025 |
| Mo | 0.25 | | 0.25 | 0.35 | 0.00249999 |
| N | 0.1 | | 0 | 0.2 | 0.005 |
| Nb | 0 | | 0 | 0 | 0 |

The material data can also be run in an Advanced modus.

By doing so you may do the following:

- Adjust the minimum and maximum values for the chemical elements
- You may alter the steps in the slider
- You may add chemical elements which were not added in the material composition of the material you selected.

Please note: If a chemical element has a minimum and maximum value equal to zero then the slider will be void and can not be used.

If a numerical value is entered which is above or below the max or min value then a red border will be seen on the value box,

References.

For calculation of HAZ and cooling time:

Yurioka <http://homepage3.nifty.com/yurioka/exp.html#E1>. Basic formulas found here with references to additional papers

Rosentahl

Calculation of preheat: EN1011-2.

Appendix A

Understanding equivalent carbon content – Ce. A review of literature

General

The welded joints in a welded structure should serve the planned loading of the structure with safety.

If there are some non-conformities around welding then the welded joint(s) under load can fail.

The welded joints could be classified according their quality. If high load and high safety is needed then high quality welded joint(s) should be produced, etc.

During production some non-conformities could occur, because welded design is not “friendly” for the appropriate welding activity or on the other hand, the parent material(s) used (prescribed) are technologically (e.g. during welding) not properly treated, and welding parameters used could be not suitable. In this latest case it means that the heat input and thermal history could be not correct.

In this context the characteristics of parent material mean chemical composition, thickness of parent materials and mechanical strength of steel grade, etc.

Alloying, chemical composition, hardness and weldability [12]

Alloying and chemical composition

The basic characteristic features of a metal could be changed in molten (fluid) status by adding some other elements – this is alloying and the added element(s) are alloying elements. If adding some small quantities of other molten metal or metals to the molten base metal, this activity is called alloying. The result after cooling is a solid stage it is called: alloy (or one or more component alloyed metal).

This activity will change or modify the basic characteristics of the parent metal - now in our case - that of the Fe (which will be modified and/or changed).

Therefore for the welded steel structure production chemically pure Fe is not used. The welding industry producing steel structures uses significantly Fe based alloys (Fe is the dominant element). These materials of different chemical composition are forming different types of steels. These are named in welded steel structure industry – base or parent metal.

Un-alloyed (plain, mild), alloyed and high alloyed steels:

If the accumulated ingredients (alloying elements) are $\leq 5\%$ and the rest is Fe, then this kind of steel is generally named to un-alloyed steel.

If the volume of ingredients is about 5 % - the steel is low (or medium) alloyed steel.

If volume of ingredients is $\geq 5\%$ the steel is highly alloyed steel.

Hardness and weldability

All alloying elements and thermal history (heat input and cooling rate) are influencing the properties of parent material(s) and weld (welded joint) as well.

This effect could be estimated as positive e.g. having higher strength and corrosion resistance etc. but some of effects could have negative influence on the load bearing capacity of welded joint, e.g. bringing crack (formation) into action and/or the welded joint under load will break (fail).

According to practice such negative effect could be significantly influenced by the chemical composition of steel and by some other - here not discussed - factors.

It means the chemical composition of the steel will influence *the hardness and the weldability* of the steel (the definition of weldability here is not discussed) and as a result of this the quality of the joint will be remarkably influenced.

Higher concentrations of C and other alloying elements such as Mn, Si, Mo, V, Cu, Ni will increase the hardness and decrease the weldability of the parent material(s).

Each of these alloying elements trends to influence the hardness (e.g. measured in HV and its value preferred to be about 320 – 340 HV 10), and weldability of the steel to different magnitudes.

However there is a need for making a method of comparison to judge the difference in hardness between two alloys made of different alloying elements.

Cracking

The metallurgical characteristics of steels are mainly dominated by its chemical composition. Any small changes in chemical composition of the base and filler metals could substantially increase cracking tendency.

The risk of cracking also increases with increasing hardness of the Heat Affected Zone (HAZ) in welding for a particular H (hydrogen) level and welded joint restraint.

A general indicative, which is C_e , is a useful guide to estimate and assess the possibility of cracking in (alloy) steels by comparison with the equivalent plain (un-alloyed) carbon steel. The two main problems faced in the cracking of the welded metals (welds) are *hot and cold cracking*.

Hot cracking occurs immediately after solidification in a weld, caused by the segregation of certain alloying elements during the solidification process. S, B and other elements tend to segregate excessively. They are reduced in order to prevent hot cracking.

Cold cracking also known as delayed or hydrogen-induced cracking, developing after solidification of the fusion zone nearby the HAZ as a result of residual stress. Generally it occurs below 200°C, sometimes several or even days after welding.

C_e sometimes is useful in planning welding procedures. Adaptability (usability) of C_e is limited if only the chemical composition of steel is considered, because the section size being welded and joint restraint is of equal or sometimes greater importance than the value of C_e , because of their strong relations to heat input and cooling rate (they are issues in details here not discussed).

Susceptibility to cold cracking is determined by hardness of welds (HAZ and weld metal – see above). The weld hardness is determined by an interactive effect of weld hardenability and carbon content.

Preheating [11]

The objective of preheating is to effuse diffusible hydrogen out of welds to prevent hydrogen assisted cold cracking.

The occurrence of cold cracking is influenced by the following factors:

- chemical composition of steel,
- thickness of parent metal(s) or plate, or wall thickness,
- weld metal diffusible hydrogen content,
- welding heat input,
- welding residual stresses or weld metal yield strength,
- weld joint restraint,
- notch concentration factor at weld toe and weld root or groove shape,
- weld pass number,
- preheating method (heating rate, heating width),
- ambient temperature,
- immediate post-heating.

Here in this study we are dealing only with chemical composition.

Carbon equivalent (Ce)

Steels can be assessed in terms of the Ce which scales the concentration of each element by its ability to retard the γ/α transformation.

“Ce” is an empirical value, relating to the combined effects of different alloying elements used in making of carbon and/or alloyed steels to an equivalent amount of carbon.

The resulting equivalent carbon coefficient allows the alloy to be compared with un-alloyed (plain) carbon steels to predict their weldability and hardness properties.

Relating to welding Ce governs the hardenability of the parent metal. It is a rating of weldability related to C, Mn, Mo, Cr, Ni, Cu, and V content.

Application of the Ce is modified by the inclusion in a steel as inclusions can effect hardenability and susceptibility for forming crack.

The most common formulas for Ce to evaluate weldability depends if the metal is any alloyed steel or modern carbon steel (see later).

The order of magnitude for Ce can be calculated using mathematical equations. There are also several commonly used and empirically derived Ce equations as well. These Ce values for expressing carbon equivalent are developed by different welding research organizations and metallurgical industry (see later).

In the practice it could be possible for each single steel grades to develop a special Ce value based on experimental laboratory practices, because these relationships could'nt be derived pure theoretically.

The alloying (constituent) elements in steel are expressed in weight percent amount (**wt%; %**), the unit of chemical composition in wt% of steel.

However steels could be classified on practical base and industrial practice, therefore generally it is enough for individual steel grades (un-alloyed, alloyed steel , etc.) to derive a formula for Ce which later could be commonly used for that particular grade of steels (see later).

The Ce is a measure of the tendency of the weld to form martensite on cooling and suffer hydrogen induced cracking therefore some preheat predictive method uses Ce as well to determine the thermal history.

By varying the amount of carbon and other alloying elements in steel, the designed strength levels can be achieved by proper heat treatment.

A better weldability and low temperature notch toughness can also be obtained.

Since Cr and Mn increase the susceptibility to hydrogen assisted cracking and hardenability of steel, the value of both indicators **P_{cm}** and **C_{eIIW}** (see later) are strongly influenced by these alloying elements.

Ce values for different steel grades and industry usage:

1/ General rules:

There are some recommendations for content in weigh % for some of alloying elements: [10, 12]

| Alloying elements | Composition | |
|-------------------|------------------|-------------|
| | Preffered (in %) | High (in %) |
| Carbon | 0,06 – 0,25 | 0,35 |
| Manganese | 0,35 – 0, 80 | 1,40 |
| Silicon | 0,10 – or less | 0,3 |
| Sulphur | 0,035 – or less | 0,05 |
| Phosphorus | 0,030 – or less | 0,04 |

I. rule of thumb:

- when Ce is less than 0,40 (%) cracking is unlikely,
- when Ce is between 0,40 – 0,60 (%) weld preheat may be necessary,
- when Ce is above 0,60 (%) preheat is necessary, post-heat treatment may be necessary and techniques to control the hydrogen content of weld are required.

II. rule of thumb:

- if Ce (%) < 0,14 (%) - excellent weldability, no special precautions necessary,
- if Ce: 0,14 (%) < Ce(%) < 0,45 (%) martensite is more likely to form, and modest preheats and welding with low hydrogen electrodes become necessary,
- if Ce (%) > 0,45 (%) extreme precautions, weld cracking is very likely, hence preheat (see above) in the range 100 - 400°C and low hydrogen electrodes are required.

The ability to form hard metallurgical microstructures like martensites or any other hard phases is dependent on the Ce and cooling rate of the steel involved in cooling from γ/α transformation temperature.

The higher the Ce value, the faster the cooling rate, the higher the tendency for hard, brittle phases to form during cooling period of time.

2/ Ce formula for common (low) carbon and carbon-manganese steels implemented by IIW [4, 5, 11]

The following carbon equivalent has been long used as an index representing the susceptibility to cold cracking or weldability.

Original O'Neil and Dearden's formula was simplified by IIW – subcommission – and in the last 25 years it is known as IIW Hydrogen cracking formula and it is valid for steels with low carbon content. This Ce_{IIW} intended for singée pass welding. [4]

The carbon equivalent formula, Ce_{IIW} , is one of the most widely used because it is a good measure of the hardenability for conventional steels.

This carbon equivalent satisfactorily evaluates weldability whose carbon content is higher than 0.12%.

Ce_{IIW} is preferable for common carbon steels and carbon-manganese steels, while P_{cm} is designed for modern low-carbon low alloy steels.

Steels with a Ce_{IIW} greater than 0,4 % cannot be welded successfully unless precautions are taken.

In the Ce_{IIW} formula, the alloying elements are heavily weighted compared to carbon, as shown below:

For steels $C > 0,12 - 0,18$ % C: [4, 13]

$$Ce_{IIW} = C + + + (\%) \quad (1)$$

For steels having Si in a “significant” volume: [4]

If Si content in the steel is more as before was in the steels, then a modified IIW formula (Ce_H) is for usage which takes into account the effect of Si.

$$Ce_H = + + (\%) \quad (2)$$

3/ Ce value for for low carbon, microalloyed steels, if $Ce \leq 0,18$ % C

3a/ P_{cm} (Ce) formula for modern steels, particularly for pipeline manufacture and $C < 0,11 - 0,12$ % (no more).

Ito-Besseyo Carbon equivalent: [4, 10, 11]

P_{cm} is designed for newer steels with low carbon, low alloy content. Modern low alloy steel is mostly of a carbon reduced type ($C \leq 0,11 - 0,12$ wt%).

Weldability of this type of steel is more adequately evaluated by the P_{cm} carbon equivalent, which was implemented by Ito and Besseyo in Japan and called: P_{cm} .

The effect of carbon becomes critical to HAZ if containing large amounts of martensite.

Thus, P_{cm} is a good indicator of hydrogen-assisted cracking in the HAZ because carbon is a heavily weighted factor in this formula, as shown

in $P_{cm} = Ce_{Ito-Besseyo}$ equation (3).

In the P_{cm} formula in equation (3), Ni does not raise the susceptibility to hydrogen-assisted cracking to the degree that it increases hardenability.

$$P_{cm} = Ce_{Ito-Besseyo} = C + + + + + 5B (\%); (3)$$

3b/ Dürén’s formula (from Germany) is similar for steel grades mentioned above in 3a: [4, 10, 11]

$$Ce_q = C + + + + + (\%) \quad (4)$$

4/ Ce formula for modern low carbon and/or microalloyed steels is: [10]

$$Ce = C + + + + (\%), \quad (5)$$

6/ Some other formulas:

6.1. Ce values for shipbuilding steels:

$$C_{eIIW} = C + + + (\%) \quad (6)$$

$$P_{cm} = C_{eIto-Besseyo} = C + + + + + 5B (\%); \quad (7)$$

Example:

for steel AH36 from Co. Oakley Steel – Ce = 0,38 for plate thickness less than 50 mm and Ce = 0,4% for plate between 50 – 100 mm thickness.

6.2. Ce values for stainless steels: [9]

For stainless steels and welds between carbon steels and stainless steels, the equivalent nickel content (Ni_e) and equivalent chromium content (Cr_e) - usually used together and in conjunction with the Schaffler-Delong diagram - are considered more accurate for measuring/estimating weldability.

6.3. Some new types of Ce formulas

6.3.a. Ce for steel grades: WES – 135 and WES – 136: [7],[8],[11]

$$C_{eWES} = C + + + + + + (\%) \quad (8)$$

6.3.b. C_{en} : [11]

In the recent years complicated formulas have been developed including welding parameters, effects of inclusions, chemical composition etc. According to the general view that for workshop usage without having PC to calculate is seeing to be not practical.

The following carbon equivalent considers this effect and can evaluates weldability of steel with a wide range of carbon:

$$C_{en} = C + f(C) \{ + + + + \} (\%) \quad (9)$$

where, $f(C) = 0.5 + 0.25 \tanh \{ 20 (C - 0.12) \} (\%)$

With decreasing carbon content, $f(C)$ decreases from 1.0 to 0.5. Therefore, C_{en} is close to C_{eIIW} when C is higher than 0.15% and C_{en} approaches to P_{cm} as a carbon content decreases. C_{en} is stipulated in ATM A 1005/A-00 and ASME B16.49-2000.

The newest carbon equivalent formula: [5]

C_{en} applies to both traditional steels (covered by C_{eIIW}) and low carbon low alloy steels (covered by P_{cm}) because of the hyperbolic tangent “tanh” term in the accommodation factor, $A(C)$, shown below:

$$C_{en} = C + A(C) \{ + + + + + 5B \} (\%) \quad (10)$$

where:

$$A(C) = 0.75 + 0.25 \tanh\{20(C-0.12)\}$$

In the higher C range, $A(C)$ approaches 1 and C_{en} approaches C_{eIIW} . Conversely, at low carbon levels, the C_{en} approaches P_{cm} . This behavior of the C_{en} equation is due to the “tanh” (hyperbolic tangent) function.

6.3.c. $Ce_{I, II, III}$ values

The formulas given here are also for prediction of weld metal hardness and strength as reference on the martensite or bainite formation show.

They are dependent of different chemical compositions, microstructure and cooling time ($t_{8/5}$) of steel.

The martensite hardness is determined solely by the carbon content and there is a relation in HAZ – and it is assumed that the same relation holds in weld metal.

The index for hardenability is a function of carbon equivalency and for different microstructure there can be different equations as it can be seen and study below.

a/ Ce_I :

The formula (13) is obtained by a best fitting manner against the present database the effect of Mn is non-linear as indicated as $Mn/(1+Mn)$. This means that activity of Mn decreases as Mn content increases. Ni and Cr are considered to show the same tendency – but their effects could be considered to be linear for Ni less than 3.5% and Cr less than 1.25% as it was indicated by the used database and Cu was considered not to contribute to hardenability thus Cu was ignored in (13).

Ce_I for calculating weld metal tensile strength [3, 11]:

$$Ce_I = C + + + + + (\%) \quad (11)$$

Ce_I for calculating HAZ maximum hardness [11]:

$$CE_I = C + \frac{Si}{24} + \frac{Mn}{6} + \frac{Cu}{15} + \frac{Ni}{12} + \frac{Mo}{4} + \frac{Cr(1-0.16\sqrt{Cr})}{8} + f(B)$$

f(B): an increase in HAZ hardenability due to boron, ($C \leq 0.8\%$, $N \leq 0.01\%$).

$$f(B) = f(C) \cdot 0.09 \cdot \frac{B - 0.0001}{Bx - 0.0001} \quad (11a)$$

$$Bx = 0.0004 + 0.0006 \cdot \frac{N - 0.0020}{0.0080}$$

$$f(C) = \cos\left(\frac{\pi}{2} \cdot \frac{C}{0.80}\right)$$

b/ Ce_{II} :

The case when the hardness of 0% martensite phase plus that due to precipitation hardening which arises only when $t_{8/5}$ becomes long –it is also function of Ce – in the following equation (14) the effect of precipitation hardening elements of Cu, Mo, V, Nb, Ti are relatively high, and the non-linear effect of Nb considered as $2.2Nb/(1+5Nb)$.

Ce_{II} for calculating weld metal tensile strength: [3, 11]

$$Ce_{II} = C + + + + + + + 2V + + (\%) \quad (12)$$

Ce_{II} for calculating HAZ maximum hardness: [11]

$$CE_{II} = C + \frac{Si}{24} + \frac{Mn}{5} + \frac{Cu}{10} + \frac{Ni}{18} + \frac{Cr}{5} + \frac{Mo}{2.5} + \frac{V}{5} + \frac{Nb}{3} \quad (12a)$$

c/ Ce_{III} :

The critical cooling time when martensite phases diminish and considered as an index of easiness of bainite formation – in this case Ce is as it follows:

Ce_{III} for calculating weld metal tensile strength: [3, 11]

$$Ce_{III} = C + + + + (\%) \quad (13).$$

Ce_{III} for calculating HAZ maximum hardness: [11]

$$CE_{III} = C + \frac{Mn}{3.6} + \frac{Cu}{20} + \frac{Ni}{9} + \frac{Cr}{5} + \frac{Mo}{4} \quad (13 a).$$

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[4] Norman Bailey:

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Abington Publishing – Woodhead Publishing 1994, United Kingdom (ISBN 1 85573 0928), p. 35 – 37, (on web test pages),

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[7] JIS G 3106:2008 – “rolled steel for welded structures”, - WES 135 and WES 136,

[8] JIS G 3115:2005 – “Steels plates for pressure vessels for intermediate temperature service –WES 135; WES 136.

[9] en.wikipedia,

[10] www.eng-tips.com/faqs.,

[11] N. Yurioka: Prediction of HAZ hardness of steels.

Metal Construction vol. 19. 1987. (p.217R).

<http://homepage3.nifty.com/Yurioka/exp.-Master> code by N. Yurioka – Welding Calculation – updated 2007. May.

[12] www.leonghuat.com/articles/carbon%20equivalent.htm.

[13] www.staff.ncl.ac.uk/s.j.bull/mmm373/WELDMAT.

Appendix B

Formulas used in the calculations:

| | |
|------|---|
| Ac1 | 750.8-26.6C+17.6Si-11.6Mn-22.9Cu-23Ni+24.1Cr+22.5Mo-39.7V-5.7Ti+232.4Nb-169.4Al-894.7B |
| AC3 | 937.2-436.5C+56Si-19.7Mn-16.3Cu-26.6Ni-4.9Cr+38.1Mo+124.8V+136.3Ti-19.1Nb+198.4Al+3315B |
| Ms | 521-353C-22Si-24.3Mn-7.7Cu-17.3Ni-17.7Cr-25.8Mo |
| CEI | $CE_I = C + \frac{Si}{24} + \frac{Mn}{6} + \frac{Cu}{15} + \frac{Ni}{30} + \frac{Cr(1-0.16\sqrt{Cr})}{8} + \frac{Mo}{4} + f(B)$ |
| CEII | $CE_{II} = C + \frac{Si}{24} + \frac{Mn}{2.16(1-Mn)} + \frac{Cu}{10} + \frac{Ni}{45} + \frac{Cr}{10} + \frac{Mo}{5} + 2V + \frac{2.2Nb}{1+5Nb} + \frac{Ti}{10}$ |
| | |
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| | |