

Crash course in welding of high-strength steels



The possibility of **reducing weight and costs** is what drives both the development and use of high-strength steels. Here follows a small general simple crash course in welding of high-strength steels.

Today's high-strength steels are often of the so-called **TMCP type (Thermo Mechanically Controlled Processing)** and/or **hardened and tempered (Q&T)**, there are also purely hardened high-strength steels, without subsequent tempering. This means that the rolling and cooling sequences during rolling are carefully selected and controlled to give the steels optimal grain size and microstructure.

Through this manufacturing process, the material can have both high strength and high toughness without the need for large amounts of alloying elements, which otherwise negatively affect weldability.

High-strength steels are very interesting for structures in applications that require high strength and thus low weight, for example in **offshore, construction, shipbuilding, transport and the defense industry**.

In order to achieve high strength and good impact toughness in the welded joint, there are certain things to consider when performing the welding.

POSITIVE & NEGATIVE

The positive thing is that modern high-strength steels generally have low alloy content, which means that the weldability is generally good. The risk of cracking in the base material and the risk of hard zones in the heat-affected zone (HAZ) is relatively easy to control.

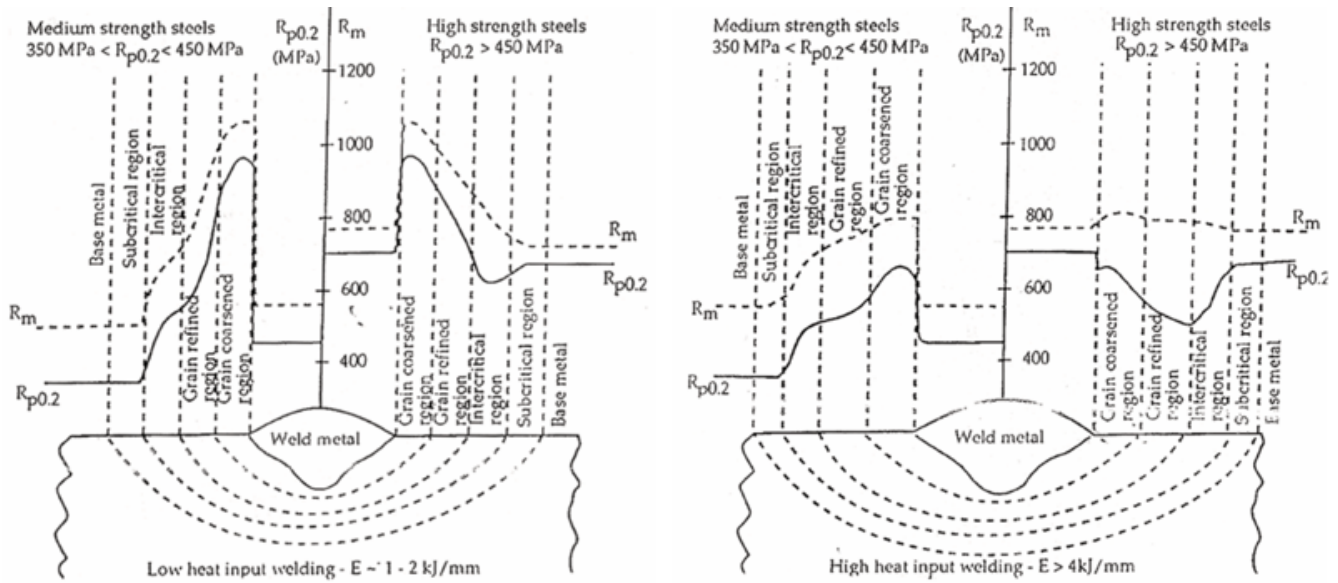
The negative part is that the carefully designed microstructure in the base material is affected by the high heat from welding, which causes soft zones in the heat-affected zone (HAZ) always formed. The width and hardness of these soft zones are primarily controlled by the already mentioned rolling and cooling sequences and alloy content used in the manufacture of the steel, as well as of course the heat input, the working temperature and the thickness of the base material. In general, of course, high heat input in thin sheet gives wider heat affected ("soft") zones.

T8/5

The cooling rate is one of the most important factors determining the outcome of a welded joint. The cooling time in seconds between 800 °C and 500 °C is the most commonly used measurement and is called t8/5. Example: The recommended delta t8/5 for a "460 steel" is 3–25 seconds and only 3–12 seconds for a "900 steel", according to a European steel manufacturer. This shows that you need to control the welding process more carefully the higher the yield strength of the steel. In practice, t8/5 is controlled by the heat input, but generally all manufacturers of high-strength steels can give you t8/5 values for their steels if you ask.

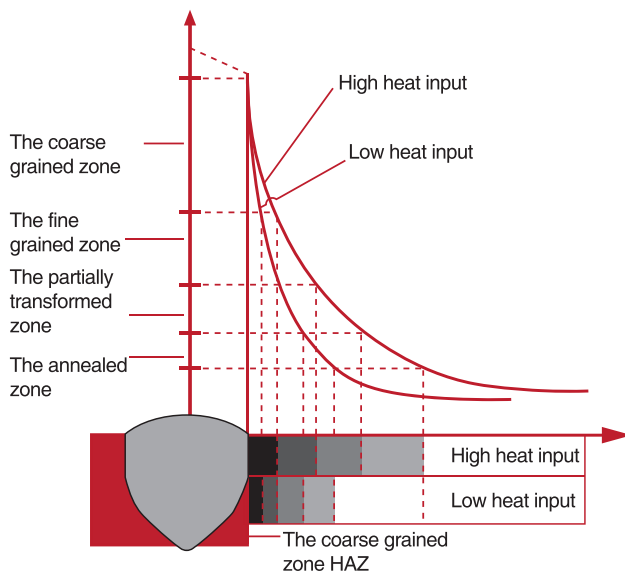
THE WIDTH OF THE HAZ

As already mentioned, during welding a soft zone in the HAZ will always form. The width, size and appearance of this zone are affected by the factors already mentioned. If the width of the zone is kept down, the strength of the welded joint is affected relatively little. Careful control and monitoring of the welding procedure is therefore important.



Akselsen, O, M and Rörvik, G. Mater. Sci. Technol 6 (april) 383, 1990

The image above illustrates the difference in what happens in the HAZ between a welded joint in a «normal» structural steel and a high-strength steel. The images show high and low heat input. Note that the image is from 1990 and the suspicion is that high-strength steel had a higher alloy content at that time, but the image is still relevant today. It is important to only heat treat these steels if it is really necessary – and then with great caution. The temperature should be kept below 600 °C, often lower. If the temperature gets too high, you risk lowering the strength in the entire heat-treated area. This also applies to hot straightening of welded structures. Always check with the steel manufacturer what applies. In general, the higher the strength of the steel, the more sensitive they are to different heat treatments.



This picture from SSAB shows the difference between high and low heat input.

CONSUMABLE THAT GIVES GOOD WELD METALS

Developing **consumables** that provide a **weld metal** that match both **high strength** and **good impact toughness** is not easy because the weld microstructure of “cast character”.

There is in principle only one way to increase the strength of the welded material and that is by increasing the alloy content. However, higher alloy content increases the risk of martensite formation, which often decreases impact toughness. Martensite does not have to be negative, which is discussed in the next section.

Balancing **alloying elements** to optimize both **strength and toughness** is therefore a sensitive task. It should also be considered that the welded material must also withstand variations in dilution and welding parameters without significantly degrading the properties.

INCREASED RISK OF HYDROGEN CRACKS

Increased alloy content also means increased risk of hydrogen cracks in the weld metal. Traditionally for unalloyed steels, hydrogen cracks have primarily been seen as a problem in the HAZ since weld metal is generally lower alloyed (mainly carbon content). As already mentioned, in high-strength weld metal there is often higher alloy contents compared to the base material. Low-alloy martensite can sometimes be a microstructure that is desirable because it enables high strengths that at the same time gives good impact toughness, but it also provides lower tolerance to hydrogen. Another negative effect of higher alloy contents in the weld metal that is linked to the above is that the transformation temperature during the cooling process decreases. The HAZ will thus first be converted to ferrite which leads to the hydrogen atoms migrating into the austenite (the weld metal) because they thrive better in austenite than in ferrite. This causes hydrogen concentration in the weld metal when the latter is converted to ferrite, which in many cases leads to hydrogen cracks in the weld metal.



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SUMMARY: THINGS TO CONSIDER WHEN WELDING HIGH-STRENGTH STEELS

- **Common carbon equivalence formulas often do not apply** – check with the manufacturer which ones apply.
- Have good control over the welding procedure. **Use recommended heat input.**
- Designers should have knowledge about **high-strength steels** so that they strive to place **weld joints in low-stress areas.**
- The cooling rate must be optimal – not too fast (risk of unfavorable martensite formation), not too slow (wide soft zone in the HAZ).
- **Filler materials** must have the lowest possible **hydrogen classification** and be kept dry and protected from moisture.
- The base material near the joint should be **clean, dry** and **free from oil and rust.**
- In general, use more passes than when welding “regular” structural steels in multi-pass procedures
- **Welding in PF** and oscillation often reduces impact strength.
- Preheat also tack-welds if required.
- Hydrogen expulsion, so-called “soaking” (200–280 °C, at least 2 h), is sometimes used for high yield strengths and thicknesses >30 mm.
- Stress relief annealing, PWHT is rarely used – often reduces strength.
- Undermatching filler metals are common, especially in low-stress areas.
- Austenitic filler metals can reduce the risk of hydrogen cracking in the joint.
- Modern high-strength steels generally have very low levels of impurities to reduce the risk of “Lamellar tearing” in the thickness direction.

The aim is that this text has been able to provide a simple and general insight into what to consider when welding high-strength steels.

The availability of expertise within Lincoln Electric on the subject is world-class and of course from the large number of experts at the producers of High strength steels.

If you have any questions on the subject, or are in the slightest doubt, you should always ask an expert.

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