Undermatching Butt Welds in High Strength Steel

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Summary

The effects of different weld geometries on the mechanical properties of undermatched welds in high strength steel have been studied experimentally. Static tension- and hardness tests have been performed on 30 individual test specimens. Three parameters were chosen to be studied; width- to thickness relation, undermatching level and the ratio between the width of the weld and the thickness of the steel plate (relative thickness). The conclusion is that the weld width and volume has a strong influence on the strength of the joint, this is due to constraint. Fractures were achieved in the base metal for joints undermatched as much as 23 %. These seemingly surprising results are explained theoretically using incremental plasticity theory.

Keywords: High strength steel, butt welding, experimental investigation, resistance, plasticity theory.

Significant improvements in steel making technologies, during the last couple of decades, have resulted in “high-performance steel” (HPS) grades, which offer higher performance in tensile strength, toughness and weld ability compared to the traditionally used steel grades. Using these steels generally leads to cost reductions, smaller sized components, lightweight structures and less welding work. The upgrading of steels requests higher demands on reliable welds, in terms of strength, fatigue resistance and safety against brittle fracture.

It is widely common to classify welds as overmatched, evenmatched or undermatched, if the yield- or ultimate strength of the weld metal is, respectively, superior, equal or inferior to that of the base metal**.** However, in very high strength steel grades, there are no overmatching or matching electrodes available and lower strength electrodes have to be used.

In this paper, the effect of the use of undermatched butt welds in high strength steel under tension is investigated. Welds were produced in coupon plates of high strength, quenched and tempered steel of various thicknesses, using flux cored arc welding (FCAW). To achieve different undermatching levels, two electrodes were used whereas one was the strongest available electrode on the market. The other electrode was chosen to give a certain level of undermatching. To decide the accurate matching levels, the actual strength of the weld metals was evaluated by static tension tests, according to ISO standards.

The joints undergoing the tests consisted of two coupons (200×1000 mm), where joint preparation and welding was performed on the longer side. A number of 30 flat tensile test specimens were then extracted from the welded joints and tensile tests was carried out. A photograph of one of the test specimens from is shown below.

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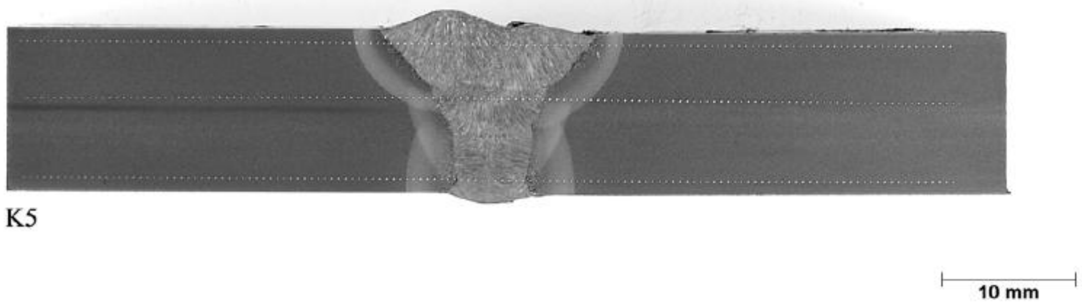

Figure 1. Longitudinal section through butt welded plates in High Strength Steel. Plate thickness 12 mm, nominal strength of base metal f_y = 1100 MPa.

Three parameters were chosen to be studied;

- Width- to thickness relation.
- Undermatching level.
- Relative thickness, i.e. the ratio between the width of the weld and the thickness of the steel plate.

As expected, both the yield strength and ultimate strength was shown to increase with increasing specimen width. It is noteworthy that the ratio between the yield and ultimate strength also was found to increase with increasing width.

For the undermatching studies, it was clear that the strength of the joints welded with the strongly undermatching wire was well above the strength of the wire material itself, thus showing the effect of triaxiality and strain hardening. A ratio between the joint strength and the base metal strength was calculated, indicating how close the joint came to achieving the base metal's strength. The global strength of the joints for Weldox 960 steel and PZ6149 electrodes was found to be governed by the base plate strength. On the other hand, when the same steel plate was welded with the weaker type of electrode, all samples failed in the weld metal.

For the last parameter studied, as expected, the strength was shown to decrease with increasing relative thickness. In almost all the undermatch cases, and for ratios between the widths of the weld to the thickness of the plate lower than unity, an apparent increase in the material strength was observed due to constraint

The performed tests show that it is possible, for the global strength of an undermatched test specimen to achieve the base plate strength. Failure was found to occur in the base metal even with an undermatching index as low as 77 %. It is also shown that if the thickness of the steel plate is kept constant and only the specimen width is increased, the global strength of the joint increases with the width of the specimens. Both the yield strength and ultimate strength increased with the specimen width, but the difference between them got smaller. This is due to constraint of the surrounding base metal which is the underlying mechanism of the large joint resistance.

When the soft weld starts to deform, the adjacent, unyielded base plate, constrains this deformation. The weld develops tension in the width & thickness directions in addition to the longitudinal direction. When the weld experiences tension in three material directions, the mean stress or hydrostatic stress in the weld is increased. Yielding of a material is governed by the Von-Mises Yield Criterion. Therefore, as the hydrostatic stress is increased by constraint, the magnitudes of the deviatory stresses which govern yielding are not increased accordingly. Thus because of constraint, larger axial stresses are required to further increase plastic strain. The mechanics of this phenomenon may be demonstrated by plasticity theory. That is mathematically done in this report.