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Original Research Article

# The influence of welding heat input on the microstructure of joints of S1100QL steel in one-pass welding

*Jerzy Nowacki* [a,*], *Adam Sajek* [a], *P. Matkowski* [b]

[a] *West Pomeranian University of Technology, Szczecin, Poland*
[b] *Teleskop Ltd., ul. Belgijska 5, 66-470 Kostrzyn nad Odrą, Poland*

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ABSTRACT

Microstructure transformations of a welded joint of the of quenched and tempered advanced high-strength S1100QL steel in relation to the heat input and its effect on the strength of the joint. The gas metal arc welding method was used with varying values of the heat input in the range from 5.5 to 7.1 kJ/cm. Metallographic examination, hardness, impact strength, and tensile strength tests were carried out. Innovative methodology of welding impact test using drop tower impact resistance tester, has been applied.

Joints with strength higher than that of welded steel were created. The amount of heat input necessary to produce joints of S1100QL steel whose strength would be higher than that of parent material was determined. The advantages of using S1100QL steel were indicated and a method of one-pass welding that allows for production of joints of optimum strength parameters with the use of mismatched filler metals was presented.

As the result of detailed weld cracking dynamics analysis of the S1100QL steel the course of joint deformation was determined as a function of time, loading force and impact energy. It was found that the dynamically loaded samples welded with lower heat input display higher limit of elasticity, which is manifested by higher loading forces and longer deformation time.



## 1. Introduction

For a few years, it has been possible for manufacturers of large-size structures industry to use modern varieties of alloys instead of classical structural steels of regular or higher strength (Table 1). Total costs and outlay of materials involved in manufacturing elements e.g. of a mobile crane structure out of steel whose yield point is 900 MPa with a product that fulfils analogous functions, but one that was redesigned, made of alloy whose Re is 1100 MPa (Table 2) prove that the following potential savings are possible:

- reduction in the thickness of cross-section of the sheets employed from 6 to 4 mm, wherefore the deadweight of the device decreases, and hoisting capacity increases;

* *Corresponding author.*
E-mail address: jerzy.nowacki@zut.edu.pl (J. Nowacki).

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**Table 1 – Comparison of the thickness of cross-section, weight and proportional values of costs of conducting selected technological processes in the course of manufacturing a comparator (length: 120 mm; width: 80 mm; butt joint with a butt weld; bending moment: 50 kNm) with the use of S355 steel and high strength structural steel S1100QL [1,2].**

| Criterion | Steel grade | |
|---|---|---|
| | S355 | S1100QL |
| Thickness of cross-section, mm | 15 | 4 |
| Weight of the comparator, % | 100 | 30 |
| Filler metal consumption, % | 100 | 7 |
| Time of laser cutting, % | 100 | 27 |
| Required bending force, % | 100 | 19 |
| Required bend radius, % | 100 | 30 |

**Table 2 – Comparison of financial costs of raw materials and selected technological procedures applied in the course of manufacturing a model element of a crane structure acting as the metallic material manufactured by the SSAB concern – Domex 900 steel, the equivalent of S900QL, and Weldox 1100, the equivalent of S1100QL [1].**

| Comparison parameter | Total cost, € of the element made of steel | |
|---|---|---|
| | S900QL | S1100QL |
| Material | 353.6 | 284.28 |
| Cutting | 2.45 | 2.83 |
| Bending | 0.013 | 0.014 |
| Welding | 15.24 | 11.31 |
| Total expenditure | 371.3 | 298.43 |

- lower spending on raw materials in case of mass production resulting from lower demand for a more resistant equivalent;
- minimisation of the costs of conducting welding processes resulting from reduced consumption of filler metals and shorter working times of welding passes of smaller cross-section areas;
- increased attractiveness of the product characterised by low operating costs (fuel consumption) due to its lower weight and smaller dimensions.

World-wide trend of reducing the mass of welded constructions, as well as more and more demanding legal regulations, such as guidelines of environmental protection institutions of the EU countries concerning the reduction of the mean value of exhaust gas emission to 95 g $CO_2$/km until 2020 year, suggest that in the nearest future, advanced high-strength steels will not cease to be attractive for the industry.

Forming the subject of analysis in this article the advanced high-strength steels S1100QL steel is classified as fine-grained, low-alloyed, or even micro alloyed, structural steel obtained in the process of thermomechanical rolling and tempering. Reduced content of carbide-forming alloy additions (Mo, V, Nb, Ti) along with increased content of strong austenite-forming elements (Mn, Ni) causes such steels in delivery condition to exhibit homogenous structure of low-carbon, tempered lath martensite with possible precipitates of high-melting carbides, e.g. $Mo_2C$, $V_4C_3$, NbC, and V-CN carbonitrides [3–8]. The presence of Nb and V elements is also conducive to the formation of fine grains of austenite during thermal rolling which later transform into small martensite plates in the course of hardening procedures. It is possible to increase the impact strength of such steels, for example by adding higher amounts of Ni [6–11].

UHSS steel welding because their structure causes number of problems. Joints of arc welded martensitic steels usually exhibit worse mechanical properties than analogous parameters of rough metallic alloy. The strength of such joints rarely turns out to be higher than the strength of parent material, which can be best illustrated with tensile strength tests that most frequently result in the fracture of samples in welds. Minimum strength of a joint is achieved in the process of blending filler metal with welded metallic alloy. In the lack of specific binders suitable for welding martensitic steels, in order to obtain welds of strength properties analogous to those of parent material, one should resort to medium- or high-alloy filler metals whose welding properties (expressed e.g. by carbon equivalent) are worse as compared to the steel of base material [12–14].

Welding procedures of limited heat input result in the formation of very narrow, softened areas located within the heat affected zones of joints. According to the popular view, small width of the tempered heat affected zone areas (often having lower strength properties than required) does not significantly affect the strength of the whole joints, which can be explained by the occurrence of the phenomenon of the so-called 'contact strengthening', generated by plane stresses in the less hard areas of joints.

Advanced structural steels, as compared to classical normalised alloys of similar carbon equivalent, exhibit a considerably lower tendency to cold crack in the joints [14–16].

Among the main technological problems related to weldability of high strength tempered steels, there is also the risk of local separation of layers of the material as a result of segregation of alloy elements [14–16].

The influence of welding heat input on the microstructure transformation of quenched and tempered advanced high-strength steels is fragmentary interpreted. Therefore, the aim of these studies is the process of microstructure transformations of a welded joint of this steel representative in relation to the amount of heat input and its influence on the final strength parameters of the joint.

## 2. Welding tests

A multiple welding causes repeated heating and cooling of the weld area. This causing a series of transformations weakening heat effected zone [14]. This is particularly disadvantageous to the unavailability of filler metals having a strength matching to the strength steels steel S1100QL. The authors consider one-pas welding as a way of the structure and properties of joints intended controlling constituting as a result of one-time heating and cooling the weld area.

An attempt was made to gas metal arc welded joints of S1100QL steel ThyssenKrupp XABO®1100 1.8942 with chemical composition: 0.18%C, 0.50 Si, 1.6%Mn, 0.017%P, 0.003%S, 1.45%