ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0010.2900

THE INFLUENCE OF TREATING WELDED JOINTS EDGES ON THE STRENGTH AND FATIGUE OF S640Q STEEL

Maria Cicholska

Gdynia Maritime University
Faculty of Marine Engineering
Morska Street 83, 81-225 Gdynia
tel.: +48 58 5586432, fax: +48 58 5586399
e-mail: cicha@am.gdynia.pl

Abstract

Weldable steels of high strength were discussed. The factors influencing the achievement of low grain structure that ensures high strength of these steels was explained. Traditional and modern methods of producing high strength steel were shown. The scheme of production line was shown, the line which is used to manufacture steel of high strength in thermomechanical way. The methods of achieving strength to fatigue used for welded joints were presented. The factors influencing the increase of strength to fatigue of welded joints were elaborated. The thermally hardened steel sheets of high strength weldable S640Q steel underwent research. Basic mechanical properties of this steel were indicated. The results of static tensile test and technological bend test were given. Then the sheets were welded by semiautomatic MAG method. The examinations of welds quality were conducted and their usefulness for further tests was stated. Mechanical properties of welded joints were determined. The mechanical properties of native material and welded joints were compared. The microstructure of welded joints in the weld axis, in heat influence zone as well as in native material was examined. Fatigue tests in a non-symmetrical cycle of lengthening – compressing for the welded joints were carried out. The computational strength to fatigue was determined and compared with fatigue strength of welded joints. Tests results were elaborated by the statistical analysis of linear regression. After conducting fatigue tests, the Wöhler diagrams were made. Afterwards, the joints welded with TIG method, were penetrated without adding filler metal. The results were presented for the fatigue tests as well as the Wohler graph for welded joints after penetration of the joints edges with TIG method without adding filler metal. The results were compared.

Keywords: *weldability, high strength weldable steels, thermomechanical treatment, increasing fatigue strength, fatigue strength.*

1. Introduction

The development of steel constructions has lately been related to the gradual increase of their size, deadweight and more complex requirements being imposed. The construction engineers started to apply steels characterized by higher strength qualities. [1, 4]. However, the increase of strength is often connected with the decrease of such properties as plasticity and weldability. The introduction of new production technologies as well as heat or plastic treatment enabled the achievement of materials of high strength without lowering their plastic properties [2, 3, 5]. High strength qualities can be obtained by:

– normalization, where carbides, nitrides and carbon nitrides are created,
– heat hardening (fine grain structure is gained by adding micro alloy elements and emitting carbides and carbon nitrides of these elements),
– thermomechanical rolling [8].

Welded steels of high strength must be characterized by good cleanliness, plasticity and good resistance to corrosion. They should also show low anisotropy of plastic properties in both rolling directions and in steel sheet thickness [12]. Good cleanliness is achieved by the application of extra metallurgic treatment such as re-blowing liquid steel with argon of powdered calcium flux or rare earth alloys [4, 5]. During the metallurgic process, the runner is cut after leaving the crystallization. Next, it is heated to rolling temperature and is subjected to a controlled thermo-mechanical rolling. This process consists in a controlled CR-rolling, which can be accompanied by rapid AC-cooling or direct annealing, and tempering DQ-T [12]. Fig. 1 shows the differences in the course of conventional rolling and the controlled rolling with rapid cooling [7].

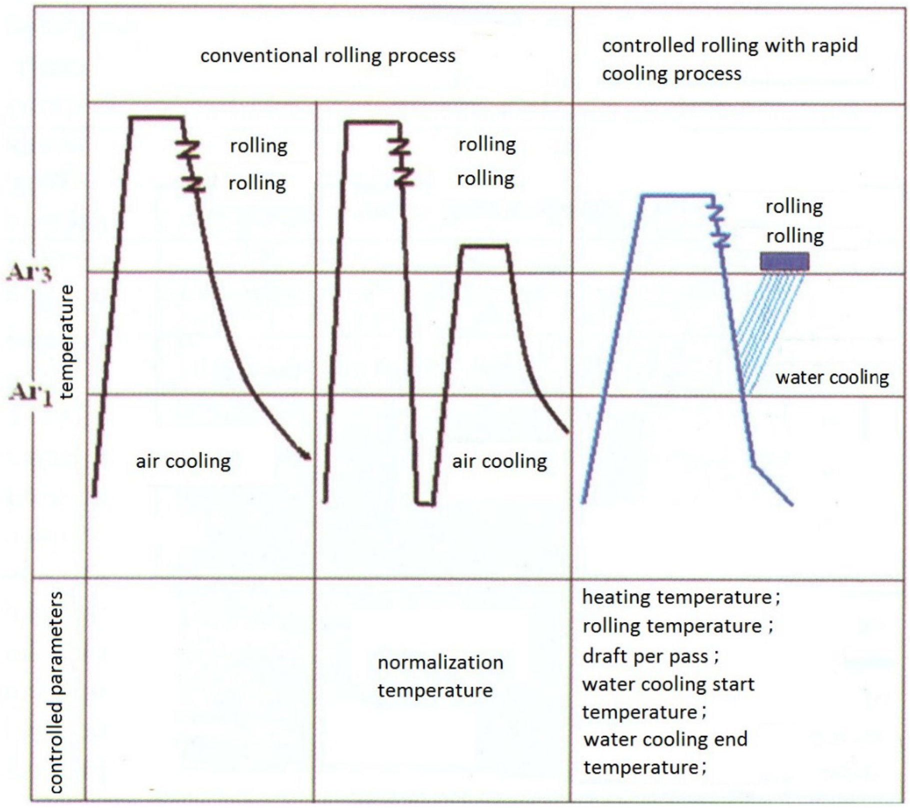

Fig. 1. Comparison of rolling processes [7]

The process of thermomechanical rolling was elaborated in Japan by the greatest steel manufacturers in the world. Fig. 2 depicts the production line of TMPC steel used in Nippon Steel Corporation [1, 7].

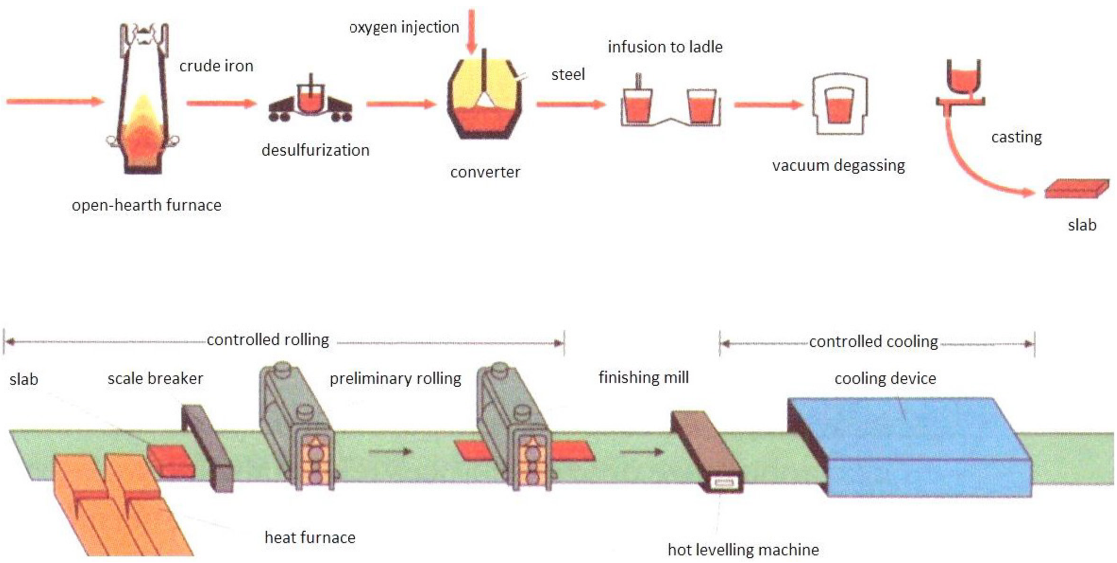

Fig. 2. Diagram of TMCP steel production line used by Nippon Steel Corporation [1, 7]

Structural steel of the highest parameters can only be applied when there is a possibility of welding it with widely used arc methods. Thermally hardened steels obtained in a thermo-mechanical process give such possibilities. The level of fatigue strength of welded joints is another crucial factor if the steel is to be utilized for the constructions that are constantly stress loaded. It is well known that welded joints show lower fatigue strength than native material. This fact can encourage constructors and technologists to look for new methods of improving the level of fatigue strength.

Methods that influence the fatigue strength of welded joints comprise:
– heat treatment,
– plastic treatment,
– shaping the geometry of welded joint.

The fatigue strength can be increased by the following actions:
– changing the weld shape which can decrease the stresses concentration,
– changing the value, type and distribution of stresses in welded joints,
– removing or easing the acuity of outer flows of welded joints in the entering area of weld nobs into the native material as well as weld inner flows,
– changing the structure of welded joint in the area of fatigue crack initiation and development,
– changing the centre where the welded joint stressed by fatigue is found.

2. Research

The research was conducted on quenched steel sheets 12 mm thick made of S640Q steel. Tab. 1 presents chemical composition of the steel examined.

Tab. 1. Chemical composition of S643Q steel according to metallurgic certificates

Steel sign	Chemical composition, % of mass										
	C	Mn	Si	P	S	Cr	Ni	Cu	Mo	V	Nb	Al
S640Q	0.19	1.45	0.29	0.021	0.020	0.02	0.01	0.03	–	0.01	–	0.04

Welding was carried out by semi-automatic MAG method. The filler metal, the scheme and welding parameters were identical as in paper [4]. Butt welds were performed without preheating while keeping the interlayer temperature of 100°C and welded semi automatically in the shield of 80% Ar and 20% CO_2 mixture on the copper plate, with Y welds. Fig. 3 presents the scheme of welding.

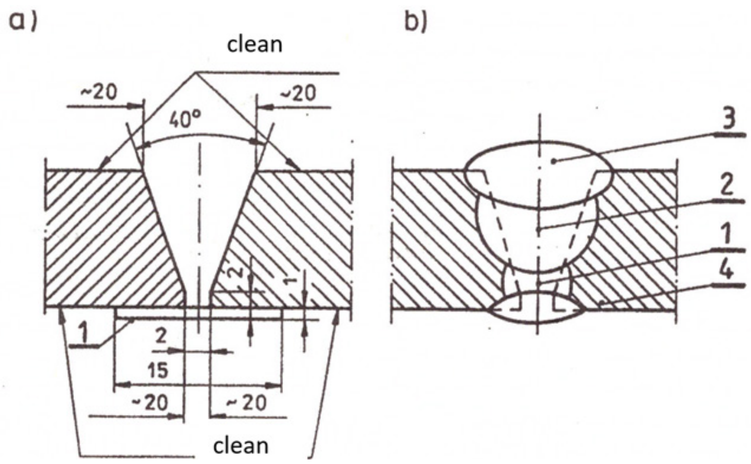

Fig. 3. The scheme of welding: a) sheets edges preparation: 1 – copper pad, b) welding sequence: 1 – before penetration run, 2 – filling run, 3 – closing run

In one weld, the nobs edges were penetrated by TIG method without adding filler metal. In order to penetrate the weld nobs a strip of native material 20 mm wide was cleaned to shining metal surface. Wolfram electrode of 3 mm in diameter was used for penetration. The distance of the electrode from the penetrated edge was kept in the range of 0.5-1.0 mm. Current intensity was 240 A, arc voltage was 14 V, the speed of penetration reached 160 mm/min, the linear energy was 12.6 kJ/cm, while the argon output was 9 dm^3/min.

X ray tests confirmed the achievement of correct welds.

In order to assess the usefulness of the welded joints, a static tensile test was carried out as well as technological bend test. Mean values of the tensile strengths obtained for given welds are shown in Tab. 2.

Tab. 2. Mechanical properties of quenched sheets of S640Q steel and their butt-welded joints

Steel sign	Samples	YS [MPa]	UTS [MPa]	EL [%]	YS/UTS	UTS_w/UTS_m
S640Q	Native mat.	638	715	16.0	0.892	–
	Welded joint.	–	745	–	–	1.04

Bending tests were performed on flat transverse strips with the use of bending arbour 36 mm in diameter. Cracks occurred at the angle of 70 ^{d}uring lengthening at the back of the weld. The root of the weld showed no cracks at the bend angle of 180°. Most samples suffered cracks on the lengthened surfaces in the joints transition area.

The welds microstructure was observed in the weld axis, in the heat influence zone and in the native material. Steel microstructure was classified as low carbon, tempered martensite of layered construction. The differences in microstructures of particular weld zones were observed. They appeared to be most clear in the observation line approximately 1 mm distant from sheet weld surface. These were typical structures for welded joints such as dendric structure of weld, overgrown grains in the overheating zone, fine grain normalization zone and the zone of partial transformation at the entrance of HAZ into the native material. No metal discontinuities were observed in the welded joint.

The computational fatigue strength was determined for welded joints of UTS_w – 165 MPa.

Samples of the shape and dimensions given in Fig. 4 were used for fatigue tests.

The fatigue tests were carried out on strength machine in a non-symmetrical cycle of lengthening – compressing, with the asymmetry coefficient of $R = -0.3$, at the load changes frequency of 16.7 Hz, with air-cooling in room temperature. Fig. 5 presents the Wöhler diagram for welded joints of quenched sheets of S640Q steel 12 mm thick. Fig. 6 depicts Wöhler diagram for welded joints after weld penetration by TIG method without adding filler metal.

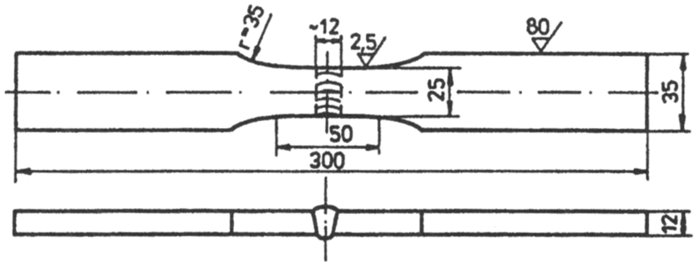

Fig. 4. Samples used for fatigue tests with weld nobs left in place

3. Remarks on research results

Literature [1, 2] assumes that quenched steel of high strength show lower weldability in comparison to steel of lower strength grade [7, 9, 11]. Welding high strength steel can therefore cause the following problems:

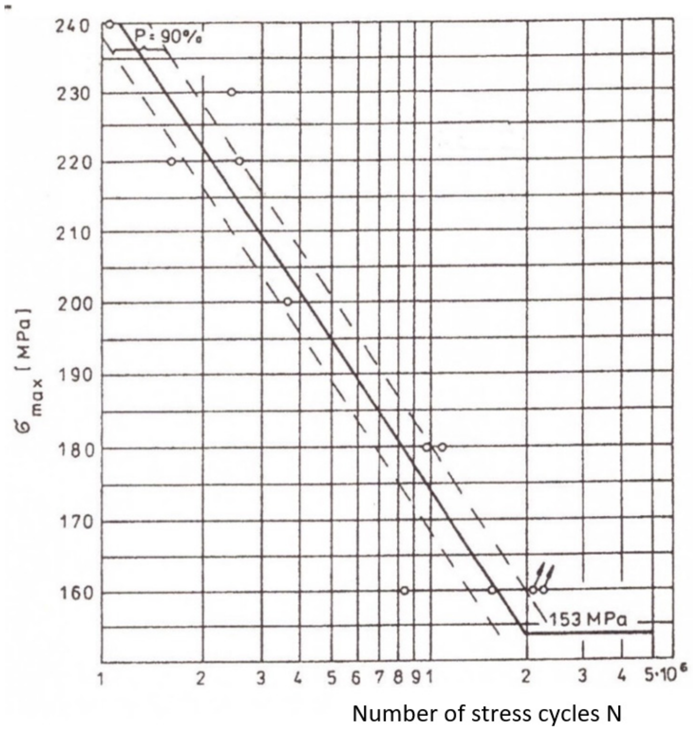

Fig. 5. Wöhler diagram for welded joints of quenched sheets 12 mm thick of S640Q steel with R = –0.3

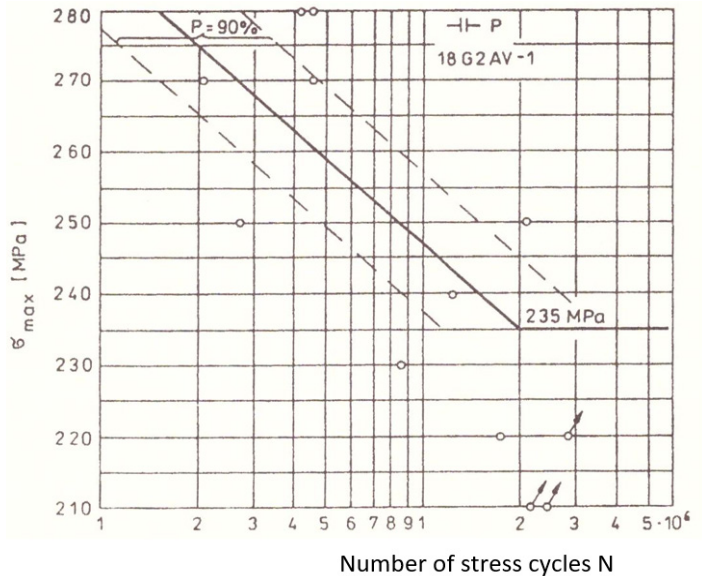

Fig. 6. Wöhler diagram for welded joints of quenched sheets 12 mm thick of S640Q steel where R = 0.3 and welds edges were penetrated by TIG method without adding filler metal

– cold cracking is likely to occur, which is due to the presence of martensite,
– decrease of ductility can occur in the area of heat zone,
– bainite structure can occur when welding at arc high linear powers, which also decreases ductility.

During the research, this relation was not proved. S640Q steel is characterized by satisfactory welding quality. Although steel contained martensite structure, X-ray and metallographic examinations demonstrated that sample welds were metallically clean. These results were obtained without applying special welding conditions such as: preheating or linear energy limitation. The presence of microstructure differences in particular weld zones can affect the level of fatigue strength. Variable microstructure in welded joints forms a structural notch.

Tensile strength of the welds was better than that of native material. The ratio of plasticity border and tensile strength amounted to 0.892. It seems important to take this fact into consideration when calculating permissible stresses for constructions made of these steels, which can increase the safety factor. When bending butt welds of S640Q steel, no cracks occurred at the bending angle of 180° on the root of the weld, while the back of the weld showed cracks at an angle of 70°. Basing on classification societies regulations it is possible to state that S640Q steel is characterized by a satisfactory plasticity.

It was discovered that fatigue strength of welded joints of S640Q steel is lower than the defined computational strength for this steel. The fatigue strength of raw welded joints was 158 MPa. The fatigue strength of welded joints after joints penetration by TIG method increased to 235 MPa. Penetration of weld edges in S640Q steel resulted in the increase of fatigue strength by 49%.

4. Conclusions

- Welding sheets of quenched S640Q steel with semi-automatic MAG method without applying any special conditions allowed to achieve welds of metallic continuity and required utility.
- Computational fatigue strength of welded joints is higher than the one determined during fatigue tests. The difference is 7 MPa.
- Fatigue strength of welded joints was increased by 49% as a result of penetration of weld nobs edges with TIG method without adding filler metal.
- The increase of fatigue strength is related to the decrease of geometric notch on the edges of weld nobs.

References

[1] Besu, B., *Microstructural variations in high-strengh structural steel weld under isohead input conditions,* Welding Journal, No. 11, 2002.

[2] Brózda, J., *Spawalność stali o wysokiej wytrzymałości,* Opracowanie Instytutu Spawalnictwa w ramach SPUB, 2005.

[3] Cicholska, M., Czechowski, M., *Materiałoznawstwo okrętowe*, Skrypt AM w Gdyni, 2012.

[4] Cicholska, M., *Analiza przydatności ulepszanych cieplnie stali 15G2ANb, 18G2AV-1 i 14HNMBCu na konstrukcje koparek*, Rozprawa doktorska, Politechnika Gdańska, Gdańsk 1994.

[5] Cudny, K., Bugłacki, H., Krzysztofowicz, T., Puchaczewski, N., *Metaloznawstwo Okrętowe*, WPG, Gdańsk 2002.

[6] Det norske Veritas, *Rules for clasification steel ship, Part 2, Chepter 3, Section 2, Welding procedure and approval of welders*, Oslo 2010.

[7] Górka, J., *Spawalność stali obrabianej termomechanicznie o wysokiej granicy plastyczności*, Biuletyn Instytutu Spawalnictwa, 5/2010.

[8] Holzner, A., *Spawanie wysokowytrzymałych drobnoziarnistych stali konstrukcyjnych metodą MAG drutami proszkowymi*, Biuletyn Instytutu Spawalnictwa, 4/2011.

[9] Pilarczyk, J., Zeman, W., *Spawalnictwo dziś i jutro*, Biuletyn Instytutu Spawalnictwa, 5/2012.

[10] Polski Rejestr Statków. *Przepisy klasyfikacji I budowy statków morskich 1990*, T. 7, Cz. IX, Zmiany nr 1/2009, Gdańsk 2009.

[11] Węglowski, M., *Nowoczesne stale ulepszane cieplnie – własności i korzyści z ich zastosowania*, Biuletyn Instytutu Spawalnictwa, 4/2012.

[12] Zeman, M., Sitko, E., *Przegląd stali wysokiej i bardzo wysokiej wytrzymałości*, Biuletyn Instytutu Spawalnictwa, 3/2007.