

THE EFFECT OF THE WELDING PARAMETERS ON THE PROPERTIES OF THERMOMECHANICALLY ROLLED HIGH STRENGTH STEELS

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INTRODUCTION

In our days, the high strength steels play an important role in the design and construction of the welded structures. Under the different demands of applications (e.g. frames, cranes, bridges), complex expectations are developed with the materials, and the material innovation must follow these tendencies; for example beside the increased strength, preservation of the more formability. These constructions are often under cyclic loading conditions, so their typical damage form is the fatigue, which means even more complex expectation with the base material.

The application of the modern high strength steels obtains an important role in these areas. In such cases, the thickness of the structural elements can be decreased altogether with the mass of the structure and the welded joints. Beside of the economic benefits, it is advantageous to the mechanical characteristics. In general, we can state that the increasing of the yield strength, the applied thickness decreases, so the amount of the filler material and the time of the welding decrease, as well. On the other hand, it is important to note, that these steels cost are two or three times higher than the average steels, furthermore the filler material costs for these steels are higher, and the weldability of these materials are more complex [1]. At the same time, the typical manufacturing technology is the welding, which – because of the heat input – modifies the original microstructure of the base material. Therefore, we achieve different mechanical characteristics (e.g. strength, toughness, hardness distribution), which is not acceptable in many cases in terms of the construction. Consequently, there is great significance of testing the welded joints of these steels, and the development of the suitable manufacturing technology.

Accordingly, the properties of VOESTALPINE ALFORM 960M (S960M) thermomechanically rolled high strength steel were summarized. The weldability of these steels were introduced too, especially the effect of the linear energy.

During our experiments, 15 mm thick base materials were used. The main reason was that these steels are frequently used in mobile crane, scraper and bulldozer structural elements, where the typical thickness is more than 15-20 mm. The direct investigation of these heavy plate thicknesses is not practical, because of the high costs and the long testing times, so we made a compromise with 15 mm thickness.

THE EXAMINED THERMOMECHANICALLY ROLLED MATERIAL

There are several possible ways to increase the strength of metallic materials (e.g. grain size reduction; formation of a complex phases, like the duplex, triplex and

twip steels; precipitation hardening of the maraging steels). In the case of the examined heavy plate thickness range, with grain refinement and change of the second phase quality, size and distribution, higher strength can be reached effectively. Among the fine grained high strength steels, the highest strength steels are the quenched and tempered (Q+T), and the thermomechanically rolled (TM) steels.

Recently the strength of TM steels is not as high as the strength of Q+T steels. At the same time, the transition temperature can be lower than with the Q+T steels, and the weldability can be more easier as well. Furthermore, the available steel plate thicknesses at the TM steels are smaller than the Q+T steels. This connection can be seen in Fig. 1 [2].

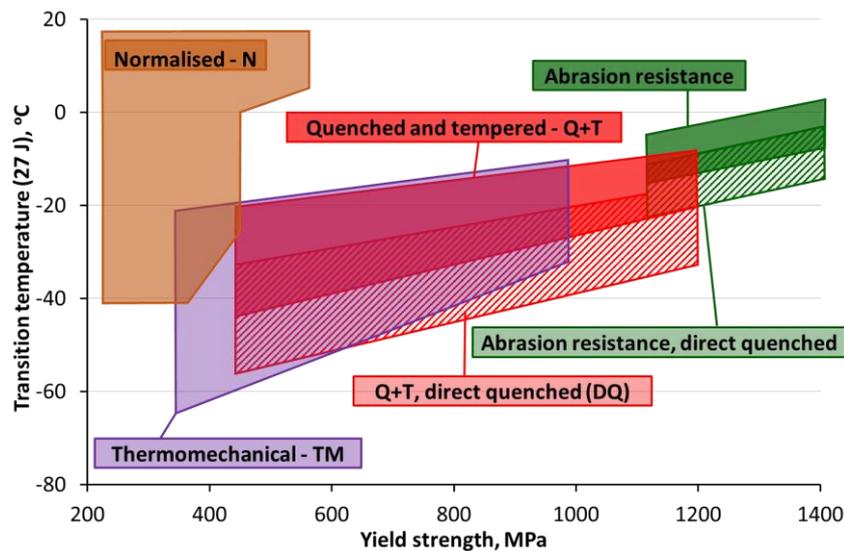


Fig. 1

Yield strength vs. transition temperature for different high strength steel types [2].

The mechanical properties and the chemical composition of the selected base material are as follows: $R_{p0.2} = 1051$ MPa, $R_m = 1058$ MPa, $A_5 = 17\%$ and $KV (-40^\circ\text{C}) = 177$ J, $C = 0.09\text{wt}\%$, $Si = 0.32\text{wt}\%$, $Mn = 1.63\text{wt}\%$, $Cr = 0.59\text{wt}\%$, $Mo = 0.2\text{wt}\%$, $Ni = 0.03\text{wt}\%$.

As we can see, the carbon content of this steel is lower than the general structural steels. On the other hand, the amount of the other elements is not so different compared to the general steels. The carbon equivalent of these steels are very low, in average 0.4 (CE) and 0.3 (CET). In case of the weldability this is considerable an advantage, but on the other hand, the complex microstructure made more difficult to weld these steels. With the higher toughness and the advantageous chemical composition the resistance against the cold cracking is also higher by these steels.

Because of the small carbon content, the distortion effect of the evolved martensite is slight, we get blind quenching. Namely, the outstanding strength of these steels can be achieved not only with heat treatment, but with alloying and with using of special production technology. In the course of this, firstly they use hot forming at 1100°C , after that cooling on air, and then heating above the A_3 temperature. After that, follow the quenching and the high temperature tempering

below the A_1 temperature, for the aim of the desired microstructure and grain size. This production process can be seen in Fig. 2 (denoted B – E) [3].

The different curves show different production methods of the thermomechanical steels. The results are the same in each case; a higher energy than the equilibrium state, and the obtained microstructure: complex ferrite matrix with tempered bainite and martensite. The determining difference is the size of the grains.

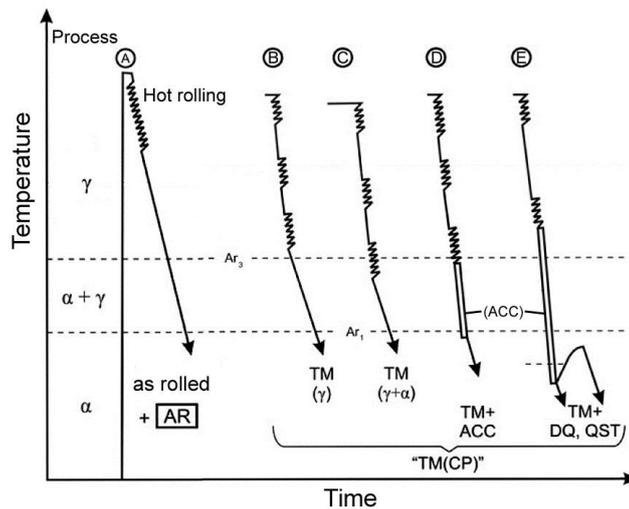


Fig. 2

Production technologies of the thermomechanically rolled high strength steels [4]

Such a microstructure can be seen in Fig. 3 part d). In favour of comparison in the figure also can be seen S355 base material (a), S690QL high strength steel base material (b) and S960QL base material.

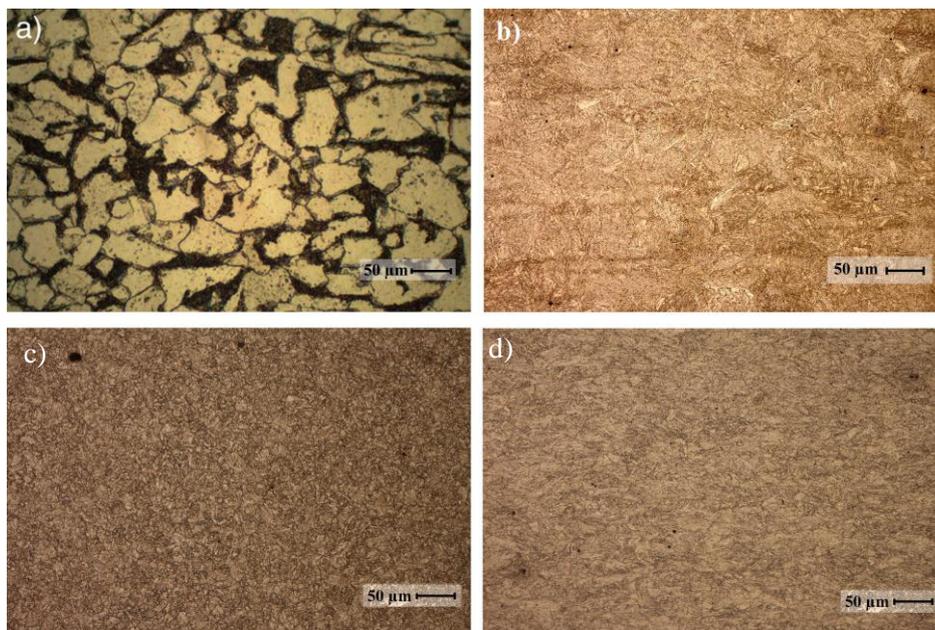


Fig. 3

Base material microstructures of different yield strength steels:
a) S355, b) S690QL, c) S960QL, d) S960M

WELDABILITY OF THE THERMOMECHANICALLY ROLLED STEELS

These steels have a higher energy after the production, than in the equilibrium state, so the obtained microstructure can be irreversibly altered during the welding process.

The heat affected zone (HAZ) can be easily hardened, furthermore, in case of too large heat input the heat affected zone can be softened comparing to the base material, which can cause strength and hardness decreasing. Of course, both cases are intolerable. Because of these effects, additional microalloys are used on this steels, like aluminium, niobium, vanadium and titanium. Of course, these feature changes also affects the fatigue properties, the different quality of the different zones in the welded joint (especially in the HAZ) significantly changes the fatigue resistance.

Besides all these, further undesirable phenomena can appear, e.g. different types of cracks. Primarily the cold cracking, to avoid the workpiece must be preheated before the welding, and it is necessary to limit the linear energy during welding. The complex tasks of the weldability of the high strength steels summarizes the Graville diagram (Fig. 4) based on the carbon content and the carbon equivalent. It can be clearly seen, that the examined base material are in the simplest weldable category (I.), while the other high strength steels locate in the hardly weldable category (III.).

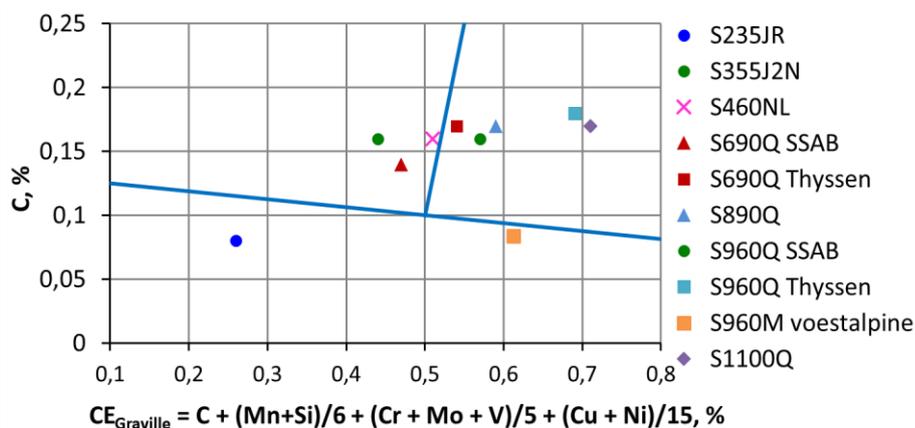


Fig. 4
Graville diagram [4]

In the case of these steels, one of the most important features of the successfulness of the welding is the heat input, which can be described with the linear energy (E_v). If the value of the linear energy is too low, the cooling rate of the welded joint may be too fast, and then cold cracks can occur. In the opposite case, strong coarse grain microstructure can be formed in the heat affected zone, which can cause the decreasing of the strength and the toughness. Therefore, we received a narrow welding lobe; inside this the quality of the joint may be suitable. Besides the previously mentioned characteristics, the material quality, the chemical composition and the applied thickness are important, too.

The $t_{8.5/5}$ cooling time was used for the common description of the welding conditions and parameters. This value shows the cooling time of the welded joint from 850 °C to 500 °C. Because of the previously mentioned reasons, the cooling time is a narrow range, which values are very dissimilar for the different heat sources. Based on our experiments and different sources the cooling time range is between 6 s and 15 s in the case of the high strength steels [5].

Since this parameter demonstrates the cooling time of the welded joint (and by this the cooling rate), this parameter closely relates to the evolved microstructure, and the evolved properties as well. The relation between the hardness and the cooling time can be seen in Fig. 5, according to the literature [3].

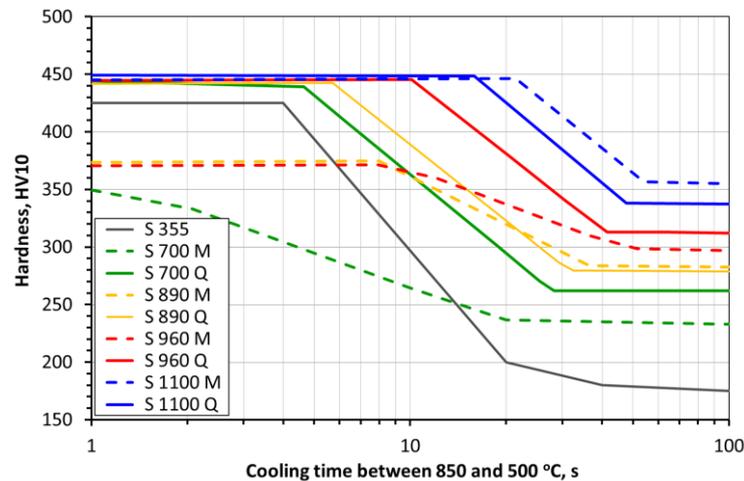


Fig. 5
Connection between the cooling time and the hardness [3]

It can be stated that with equal cooling times, the evolved hardness values are always smaller in the case of thermomechanically rolled steels. On the other hand, with the increasing of the strength, the difference is decreasing between the Q+T and TM steel curves.

In a few words,

- the TM steels not require preheating during the welding, and
- the change of the linear energy is not significant on the properties of the TM steels.

THE WELDING EXPERIMENTS

Based on the previous statements, welding experiments on S960M (VOESTALPINE ALFORM 960M) thermomechanically rolled high strength steel with 15 mm thickness were performed.

For the welding experiments gas metal arc welding (GMAW, ISO code: 135) was chosen, because these steels are welded mostly with this procedure. It is important to note, that because of the heavy plate thickness in these products, in the case of productivity submerged arc welding (SAW, ISO code: 121) can also be used, but because of the complicated products and the controlled linear energy problem this procedure is applied only in limited cases. Also, based on industrial

experiences M21 mixed gas with 18% CO₂ and 82% Ar as shielding gas was chosen. As filler material, THYSSEN UNION X96 wire with 1.2 mm diameter ($R_{p0.2} = 930$ MPa, $R_m = 980$ MPa, $A_5 = 14\%$, $C = 0.12\text{wt}\%$, $Si = 0.8\text{wt}\%$, $Mn = 1.9\text{wt}\%$, $Cr = 0.45\text{wt}\%$, $Mo = 0.55\text{wt}\%$, $Ni = 2.35\text{wt}\%$.) was applied. In the case of the filler material choosing, this means a matching condition, in other words the mechanical properties of the filler material and the base material are nearly equal. In the interest of the uniform stress distribution, X joint preparation was designed, and during the welding, the test piece was rotated regularly. For the experiments DAIHEIN VARSTROJ WELBEE P500L welding equipment was used. The dimensions of the welded plates were 300 mm x 125 mm. The experimental assembly can be seen in Fig. 6.



Fig. 6
Assembly of the welding experiments

For the investigation of the heat input effect on the welded joints, two experiments were made. In the first case the cooling time ($t_{8.5/5}$) was between 6 s and 8 s, while in the other case the cooling time was between 14 s and 17 s. Usually, these steels do not required preheating, so during the experiments no preheating was used, but the interpass temperature was 150 °C, in accordance with the experiments on S960QL steel [2]. The crucial welding parameters were recorded continuously during the experiments with the help of WeldQAS process monitoring device. The root layers were made by a qualified welder; while the other layers were made by welding automate. The applied welding parameters can be seen in Table 1.

Table 1
The applied welding parameters

Number of experiment	Layer	Current, A	Voltage, V	Welding speed, cm/min	Linear energy, J/mm	Cooling time, s
1	1-2	140	20,0	20	750	6
	3-8	255	26,5	40	1050	7
2	1-2	140	20,0	20	750	6
	3-8	300	29,0	33	1400	16

RESULTS OF THE WELDING EXPERIMENTS

Tensile tests were executed firstly on specimens cut from the test pieces, according to MSZ EN ISO 15614-1 (cross joint tensile test specimens). The results can be seen in Fig. 7. We can state, that the difference between the two experiments belonging to the cooling times is not significant (average 47 MPa).

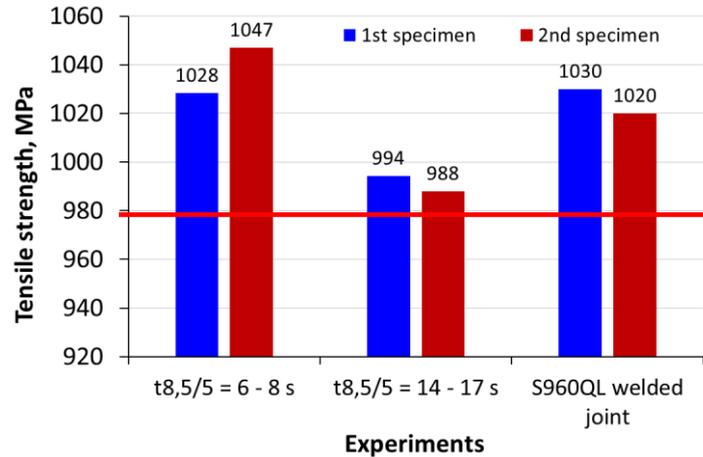


Fig. 7
Results of the tensile test

The hardness test results on the lower side of the welded joints (layer 7 and 8) can be seen in Fig. 8. Compare with the S960QL steel results [2], the thermomechanically rolled steel has a lower hardness, and the modification of the heat input (linear energy) has not significant effect on the evolved hardness.

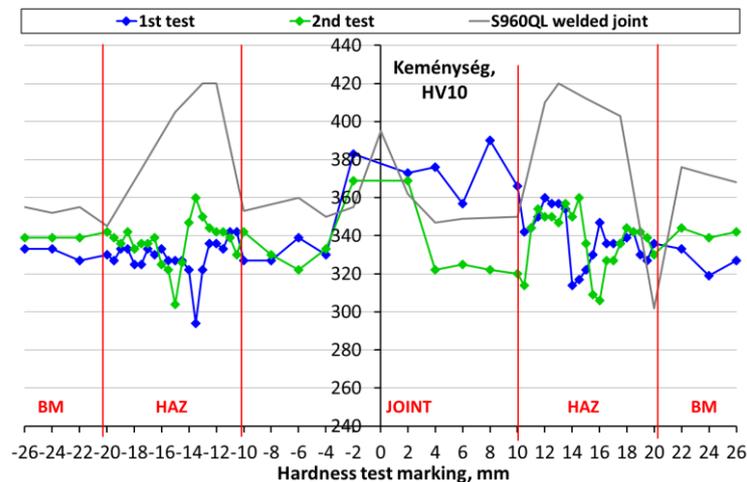


Fig. 8
Results of the hardness tests

The specimens for microstructural examinations can be seen in Fig. 9. In the case of the second experiment (higher heat input), the area of the heat affected zone and the coarse grained zone is wider, as we predicted.

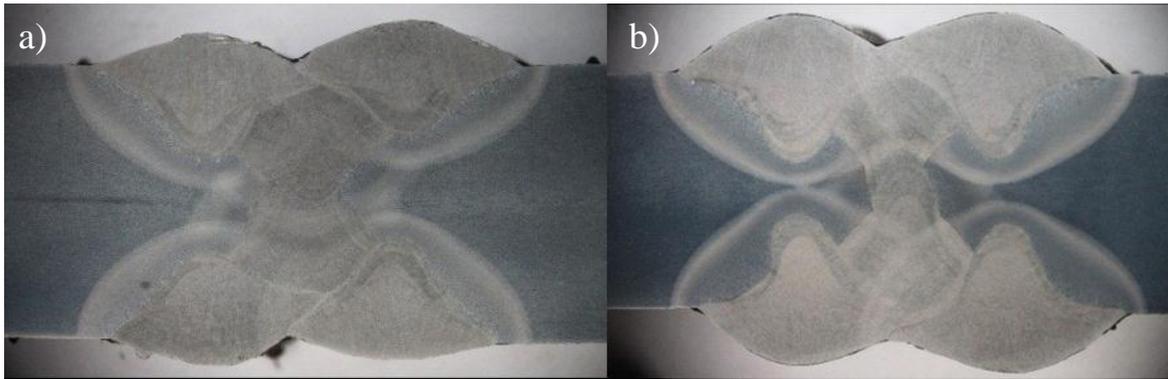


Fig. 9

Specimens for microstructural examinations: a) 1st experiment, b) 2nd experiment

CONCLUSIONS

Based on the results of the experiments, completed with the literature data, the following conclusions can be drawn.

- The modification of the heat input (along with the cooling time) effects on the mechanical properties (tensile strength, toughness, hardness) in a small way.
- In the critical heat affected zones coarse grain microstructure does not form.
- In accordance with these, on the case of the thermomechanically rolled (TM) steels, the welding parameters can be alter in a wide range, so we can use a larger welding window than by the quenched and tempered (Q+T) steels.

REFERENCES

- [1] Dillinger Hütte GTS: **Dillimax Technical Information No. III/2007**, p. 5.
- [2] **Hegeszthetőség és a hegesztett kötések tulajdonságai**. Eds.: BALOGH, A., LUKÁCS, J., TÖRÖK, I. University of Miskolc, 2015. ISBN: 978-963-358-081-3 (In Hungarian.)
- [3] RAUCH, R., SCHNITZER, R.: **Alform welding system**, Voestalpine informant, Alform Welding Day, June 2012.
- [4] WILMS, R.: **High strength steels for steel construction**, Nordic Steel Conference publication. pp. 597-604, 2009.
- [5] GÁSPÁR, M., DOBOSY, Á., LUKÁCS, J., SAS, I.: **Behaviour of undermatched AHS steel welded joints under static and cyclic loading conditions**, IIW International Conference, Helsinki, 2015. 07. 02-03., IIW2015-15/1804

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