NUMERICAL SIMULATION OF TIG-DRESSING OF WELDED JOINTS

Jörg Hildebrand[1], Idna Starcevic[2], Frank Werner[3], Heinz Heinemann[4] and Günter Köhler[5]

ABSTRACT

The TIG-dressing of weld transition allows for improving of the fatigue strength of a welded connection by reducing the sharpness of the notch possible. The melting influences the welding seam geometries, as well as existing structural conditions and residual stresses are significantly. Taking a butt joint and a cross joint as an example, the changes in the structure and in the residual stress will be shown, namely as results of a FE-simulation. In addition, the influence of the distance between two TIG heat sources on the cooling time $t_{8/5}$, as well as on the stress distribution, will be investigated.

KEY WORDS

high-strength fine-grained steel, TIG-dressing, residual stresses, welding simulation, SYSWELD®.

INTRODUCTION

With the development of new steel production methods mass fraction of the different alloy elements could successfully be changed in such a way that aa better weldability as well as higher strengths could be achieved by changing the (yield strength up to 1100 N/mm²) [Hubo and Schröter 2001]. A higher steel strength leads to a reduced material consumption, as well as to reduced processing costs especially in the case of highly stressed constructions. As far as changing/cyclical stress is concerned the behaviour of welded connections made of high-strength steel shows disadvantages as yet. The assessment of the fatigue strength in the norms presently valid, e.g. in bridge construction, illustrates this.

The deployment of dressing in the area of weld transitions of welded connections improves the notch fall, the durability, and the fatigue strength of the construction section. Thus, it becomes possible to use high-strength steel in improving stress conditions more effectively.

Numerous scientific publications are dealing with experimental investigations of the various dressing methods (Ummenhofer et al. 2005), as well as with the numerical simulation to

---

[1] Civil Engineer, Bauhaus-Universität Weimar, Dept. of Steel Structure, Marienstrasse 5, 99423 Weimar, Germany, Phone +49 3643/58-4442, FAX +49 3643/58-4441, joerg.hildebrand@bauing.uni-weimar.de

[2] Civil Engineer, idna.starcevic@bauing.uni-weimar.de

[3] Professor, frank.werner@bauing.uni-weimar.de

[4] Research Engineer, Institut für Fügetechnik und Werkstoffprüfung (IFW) GmbH, Otto-Schott-Straße 13, 07745 Jena, Germany, Phone +49 3641/2041-15, FAX +49 3641/2041-10, HHeinemann@ifw-jena.de

[5] Professor, GKoehler@ifw-jena.de

assess the vibration strength of welded connections made of high-strength steel (Hildebrand and Schliebner 2004).

At the Institute for Joining Technology and Material Testing (Institut für Fügetechnik und Werkstoffprüfung - IFW),Jena within the framework of the present research project „Improvement of the Durability Strength Values of Welded Connections made of High-Strength Fine-Grained-Steel by means of Treatment of the Weld Transitions through Pulse-Modulated TIG-Luminous Arc respectively Laser Beam“ the technological application and efficiency of the dressing methods are investigated on butt joints and cross joints. Additionally, numerical simulations on the structural changes and residual stresses as a result of the dressing were carried out at the Dept. of Steel Structure at the Bauhaus-Universität Weimar.

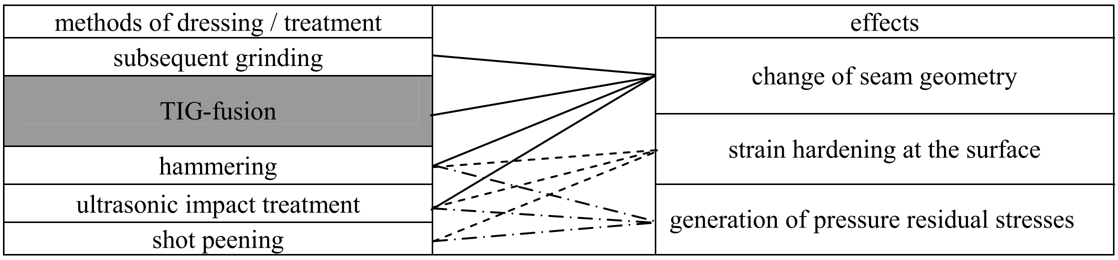
DRESSING PROCESSES FOR WELDING SEAMS

Research of the fatigue strength effects of various dressing processes on welded connections have been carried out for about 20 years now. Three different groups of processes can be distinguished:

- Geometry change at the weld transition (notch effect)
- Generation of peen hardening on the surface
- Generation of residual compressive stress on the surface

Depending on the dressing, several changes can be achieved in the welding seam at the same time (see Table 1).

Table 1: Most important dressing / treatment processes and their effects according to (Ummenhofer et al. 2005)



Due to the availability in manufacturing companies, TIG-dressing is a widely used technology. Through a melting of the material in the transition between welding seam and base material a fillet is created and, thus, the notch sharpness is decreased significantly. This process without supplementary wire should be carried out in a tray to make sure that the melting material is distributed evenly.

EXPERIMENTS

The IFW Jena produced MAG-welded butt- and cross joints made of high-strength fine-grained steel S690QL (plate thickness 15 mm) and S960QL (plate thickness 10 mm) for demonstration and investigation of a TIG-dressing of the weld transition (see Fig. 1).

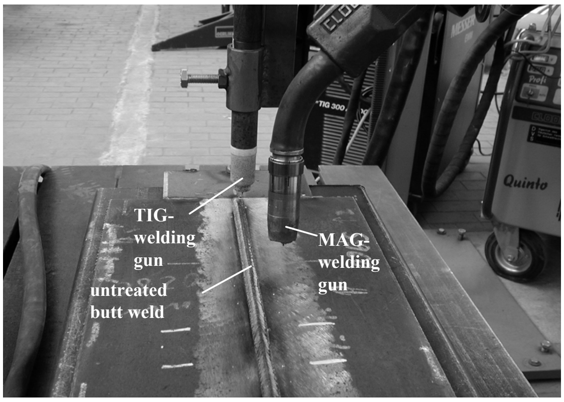
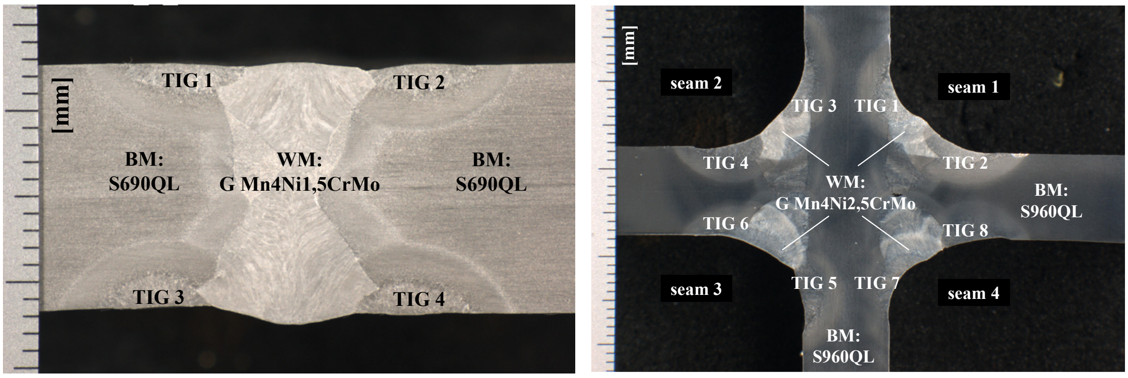


Figure 1: Experimental setup

The macro section pattern of a butt joint with the base material (BM) S690QL and one of a cross joint using GW S960QL are shown in Fig. 2. The deployed supplementary welding material (WM) and the sequence of the TIG-dressing are explained in Fig. 2.



a) butt joint b) cross joint

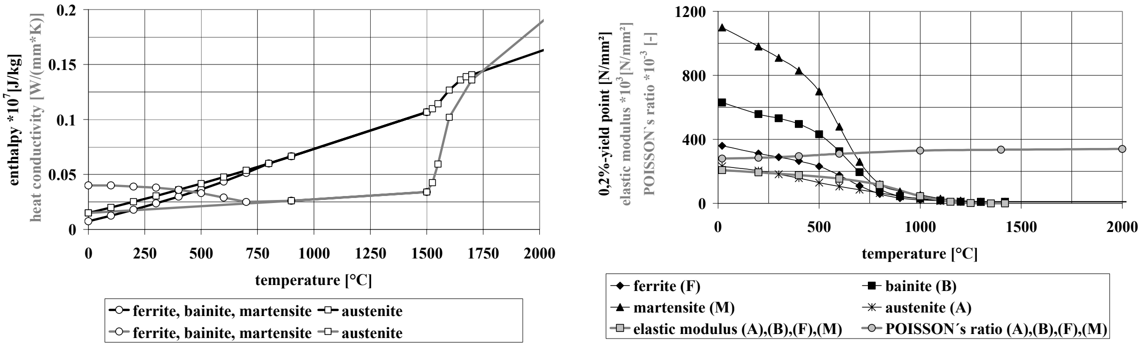
Figure 2: Macro section

The TIG-method uses a pulse luminous arc to increase the arc pressure on the batch and, thus, to improve the seam geometry. With the pulse power/pulse current variation a complete melting of the transition welding seam/base material in a welded connection can be achieved.

NUMERICAL SIMULATION

They are regarded the welding and dressing sub-processes into thermodynamics, mechanics and metallurgy for the understanding of complex physical interaction. The knowledge of the interdependence of these processes is important for the understanding. The structure condition is directly influenced by the transient temperature field. The diffusion of gases has minor influence on the temperature distribution (Wohlfahrt 2002). Thus, simplified models with a reduced computing time can be created. In principle, the literature distinguishes between calculation of the temperature field while taking into account the structure change, mechanical analysis and determination of the gas diffusion during the welding process.

For the thermal and mechanical simulation, phase- and temperature dependent material properties are used. It is to be noted that the steel consists of constituents of the microstructure and is regarded as inhomogeneous material. The steel properties in the simulation are realised by a combination of the structure properties. Based on values from the literature, the material data given in Fig. 3 is used for the individual microstructure component.



a) thermal b) mechanical

Figure 3: Used material data

The transformation processes during the heating phase can be illustrated by a continuous TTA-diagram. For the steel S355N such an illustration is given in (Degenkolbe et al. 1999). To describe the transformation behaviour of the steel S690QL and S960QL this illustration is used since no further TTA-diagrams were available in the literature.

The transformation during the cooling down phase can be described by welding-TTT-diagrams. For the creation of these diagrams a typical welding cycle was used (quick heating, slow cooling). The diagrams used for the simulation have been published in (Scharff et al. 2001) for S690QL and in (Seyffarth and Scharff 1998) for S960QL.

For the supplementary welding material older TTT-diagrams exist. These are inappropriate for today's supplementary welding material since the chemical composition and the heating up velocities for creating the TTT-diagrams do not correspond. For this reason an empirical approach was used which was first mentioned in (Seyffarth and Kassatkin 1984) and which has been further developed, to describe the transformation. The continuous structure transformation can be taken into account by structure kinetics of Leblond by means of the FE-program SYSWELD® during the simulation.

When assessing the hardness characteristics of welded hybrid connections in the area of the heat-affected zone (HAZ) of high-strength fine-grained steel a so called „hardness drop“ can be seen. This decline of hardness is not taken into account in the welding-TTT-diagrams. The hardness drop can only be explained by a tempering effect of bainite or martensite at the edge of the heat-affected zone. A mathematical description of this effect of bainite und martensite in dependence of heating up velocity and maximum temperature has been developed (see Fig. 4).

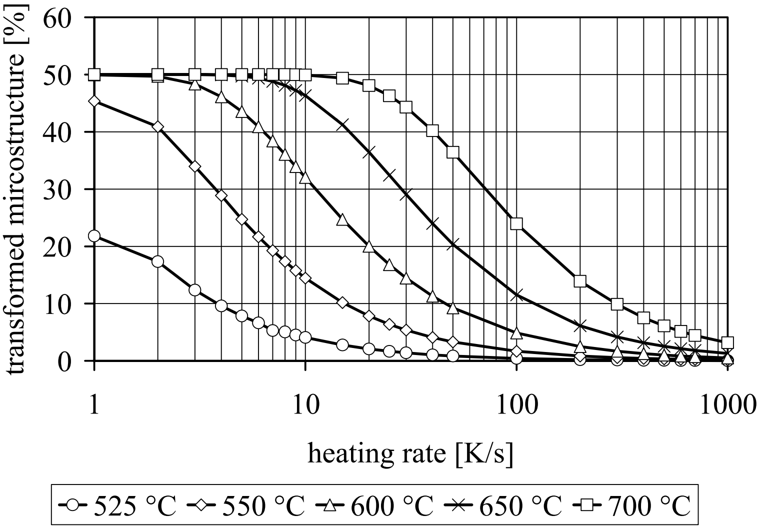


Figure 4: Transformed microstructure dependent on heating rate and temperature

For the simulation of the temperature field the material properties and the parameters for heat input and heat emission as input variables are needed. The heat input can be simulated by an ellipsoid normal source given in (Hildebrand and Werner 2004). The form of the heat source depends on the observed welding method. This makes a fitting of the heat source to according to the real conditions necessary.

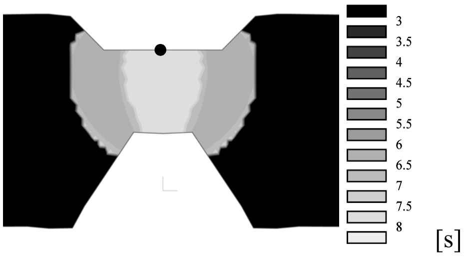
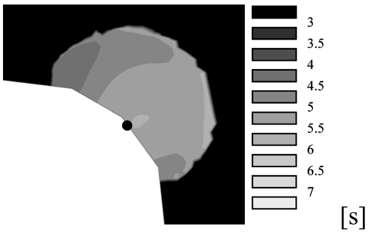
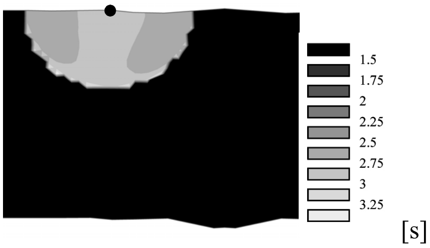
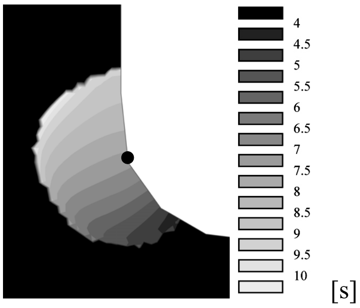
The heat emission consists of radiation and convection. The radiation is described by the Stefan-Boltzmann law and convection data is given in the literature.

RESULTS OF THE SIMULATION

The verification of the numerically computed temperature field is achieved on the one hand by comparison with the measured cooling time $t_{8/5}$ and on the other hand by comparison with the extension of the molten pool which can be seen from the macro section pattern. So energy inputs can be controlled and the temperature-dependent material values which influence the heat conduction as well as the heat storage can be examined.

At the marked points the cooling time $t_{8/5}$ of both welded connections were measured (see Table 2). Changes in the cooling time become visible: starting in the area of the welding seam, over to the heat-affected zones, ending with the uninfluenced base material of the welding. Interesting seems to be the wide spread of cooling times occurring with the TIG-dressing, using cross joints.

Table 2: Calculated cooling time $t_{8/5}$ for butt- and cross joint

		butt joint	cross joint
cooling time $t_{8/5}$	MAG-welding	 ● measuring point, measured: 7,36 s	 measured: 5,49 s
	TIG-dressing	 measured: 3,46 s	 measured: 7,16 s

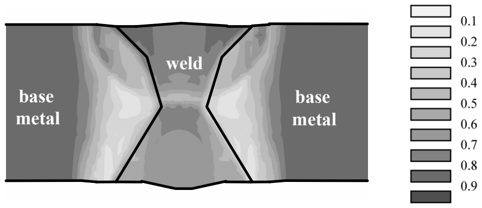
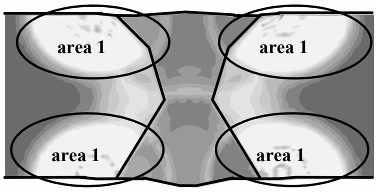
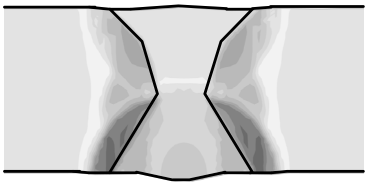
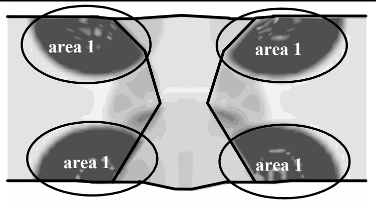
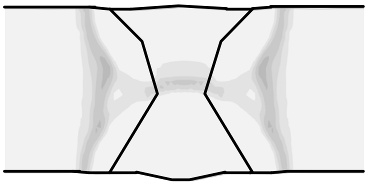
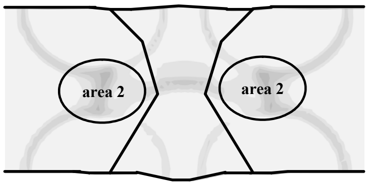
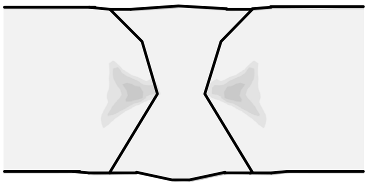
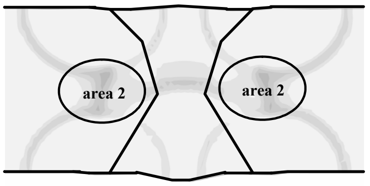
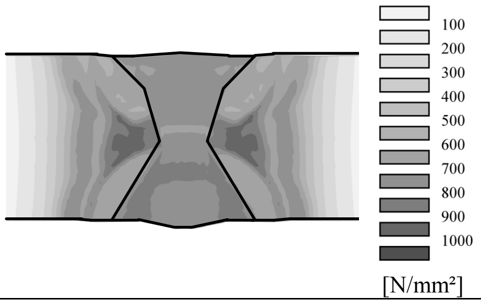
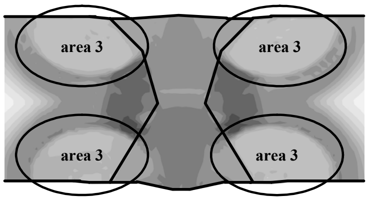
The microstructure shares and equivalent stresses before and after the TIG-dressing are given in Table 3 for the butt joint and in Table 4 for the cross joint. The microstructure after the welding changes due to the renewed heat input and partial melting. As a result of a low heat input transformation from austenite mainly to martensite and only to a smaller part to bainite (area 1) occurs. In area 2 which shows the heat-affected zone during the MAG-welding and TIG-dressing, the proportion of the tempered microstructure increases. A narrow zone of newly tempered martensite or bainite is formed surrounding the heat-affected zone.

The clear change of the residual stress can be seen by means of the equivalent stress (von Mises). It can be explained by heat impact and microstructure transformation. The zone which shows a very high residual stress after the welding becomes bigger after the TIG-dressing (area 3). A lower stress level can be achieved and a marked stress peak at the weld transition could be avoided.

The butt joint shows similar changes as the cross joint. The microstructure of steel S960QL already consists mainly of martensite and according to the welding-TTT-diagram bainite is only formed after a cooling time of about 12 s, the microstructure change of martensite and bainite will not be so significant (area 4). The supplementary welding material under MAG-welding parameters transforms mainly into bainite (area 5), which is tempered or completely molten through the TIG-dressing. A significant influence of the TIG-dressings TIG1 or TIG 2 on the composition of the structure in area 6 could not be found during the TIG-dressing

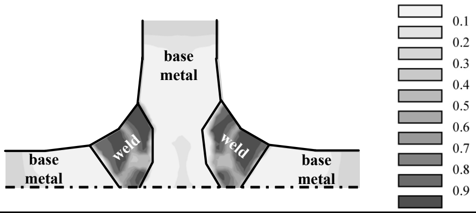
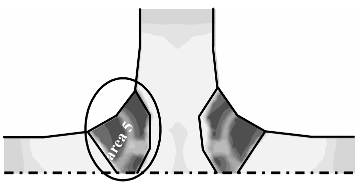
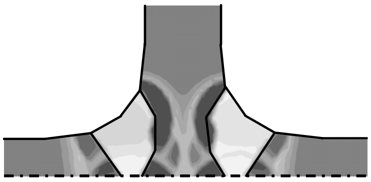
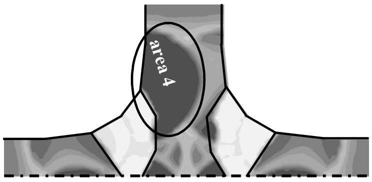
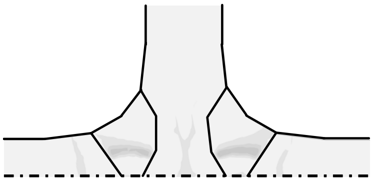
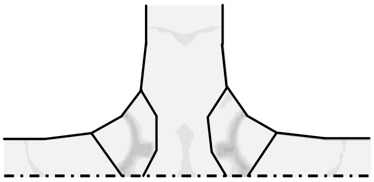
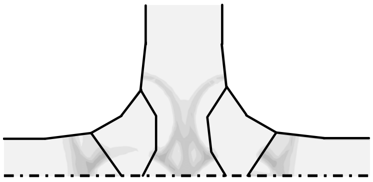
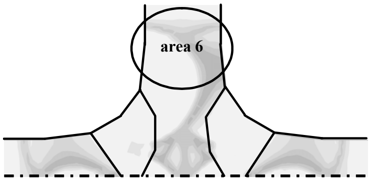
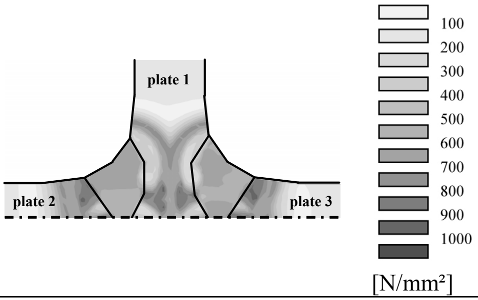
TIG3 determines the microstructure composition. This also becomes clear when looking at the equivalent stress. Before the TIG-dressing, a symmetrical distribution of residual stresses over plate 1 in Table 4 can be observed. A stress peak which is more marked at the transition between welding seam and plate 2 and 3 occurs at the welding seam transition of plate 1.

Table 3: Microstructure and equivalent stress – butt joint (S690QL)

		before TIG-dressing	after TIG-dressing
microstructure	bainite		
	martensite		
	bainite (tempered)		
	martensite (tempered)		
equivalent stress			

In contrary to this an unsymmetrical residual stress condition can be observed after completion of all TIG-dressing operations. Because of the low plate thickness of 10 mm, a low energy input and the transformation of a big amount of martensite to tempered martensite, high stresses are developed after complete cooling on the opposite side to TIG3 (area 7). An improvement of the notch sharpness can only be achieved in this case, by a geometrical change of the welding seam transition. A brittle microstructure and a stress concentration at the transition of welding seam remain in a construction.

Table 4: Microstructure and equivalent stress – cross joint (S960QL)

		before TIG-dressing	after TIG-dressing
microstructure	bainite		
	martensite		
	bainite (tempered)		
	martensite (tempered)		
equivalent stress			

One alternative to change the residual stress condition on the opposite side to TIG3 is to influence the heat conduction by varying the distance between the heat sources TIG1 and TIG2. The decoupling of both heating processes becomes also visible in the temporal change of the equivalent stress of P1 and P2 during cross joint. (see Fig. 5) Up to a distance of 50 mm between the heat sources there is a difference of max $\sigma = 50$ N/mm² between the equivalent stresses. Beyond that, the stress in P2 declines slightly. At the same time the stress in P2 rises $\sigma = 150$ N/mm².

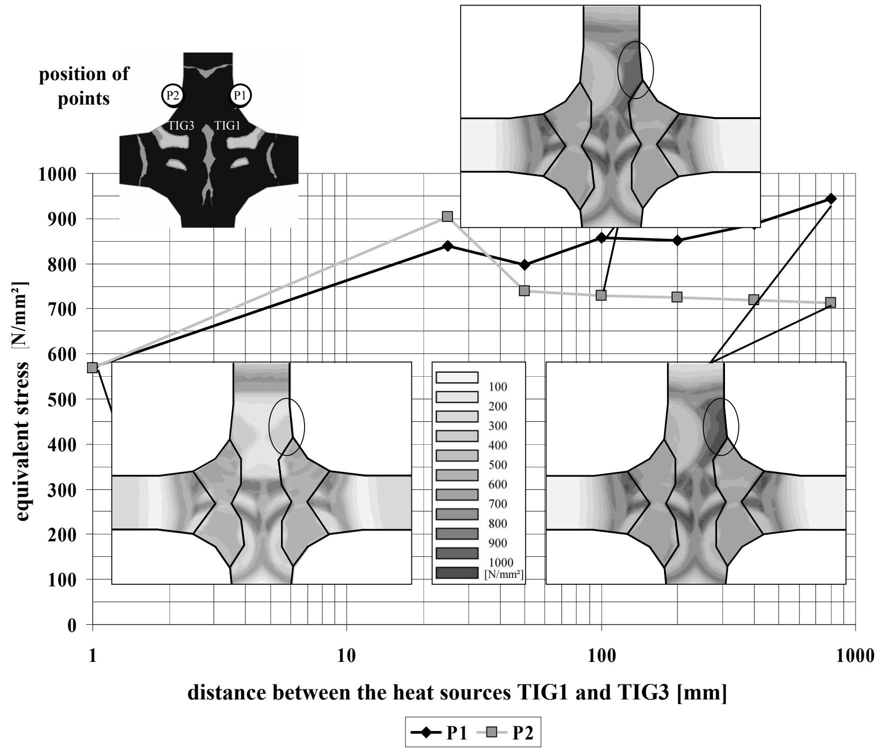


Figure 5: Change of equivalent stress as a function of the distance of the two heat sources

The comparison of measured and computed cooling times $t_{8/5}$ shows that even when partially estimated material data and transformation behaviour are used, suitable results via the numerical simulation can be obtained. Further experimental investigations as to the metallurgical assessment of the butt joint welding seam (S690QL), which was TIG-aftertreated, show clear changes of the microstructure that are in-line with the numerical results. Measurements of residual stresses of the presented welded connections in order to confirm the statements made on the basis of the numerical analysis have not yet been conducted.

CONCLUSIONS

The variation of material data for steel of dependent on alloy proportion with the same strength properties makes it difficult to give an exact description of the thermal, metallurgical and mechanical material behaviour in the FE-model. The comparison of results from experimental and numerical investigations for both welded connections although that a reasonable estimate of not exactly available data leads to usable results.

By means of a TIG-dressing operation the welding seam geometry, the structure and the residual stress conditions are changed significantly in the area of the welding seam. In the transition of welding seam a brittle microstructure (martensite) could be the result. However, the reason therefore is the low energy input and the transformation behaviour of the deployed steel (S690QL und S960QL). The residual stresses can be reduced in the case of butt joint. In the case of the investigated cross joint higher residual stresses occur on the plate opposite TIG3 than before the TIG-dressing.

The numerical investigation of the influence on two heat sources (TIG-dressing) shows that the residual stress can be reduced significantly when a TIG-dressing operation is done both plate sides, but the cooling time in the case of steel S960QL becomes too long. Thus, as far as thin plates are concerned, the required strength properties cannot be guaranteed. When the distance between both heat sources becomes greater 50 mm the separation of a heating process must be done. Again, very high residual stresses occur on the plate opposite to TIG3.

The results demonstrate that a numerical simulation is a valuable supplementary tool enriching experimental investigations. Processes and conditions can be modelled and discussed which can hardly be depicted by experiments.

REFERENCES

Degenkolbe, J., Hougardy, H. P. and Uwer, D. (1999). "*Merkblatt 381 – Schweißen unlegierter und niedriglegierter Baustähle*", Stahl-Informations-Zentrum, Düsseldorf.

Hildebrand, J., Schliebner, R. (2004) , Simulation, computation and fatigue tests of welded joints between high-strength fine-grained steels and structural steels, In: *Progress in Structural Engineering, Mechanics and Computation (SEMC)*, ed. by A. Zingoni, Leiden, London, New York, Philadelphia, Singapore: A. A. Balkema Publishers, S. 289.

Hildebrand, J., Werner, F. (2004). Simulation, computation of welded joints between high-strength fine-grained steels and structural steels**,** In: *The 8th International Conference "Modern Building Materials, Structures and Techniques"*, Vilnius: Technika, 2004. 227-228.

Hubo, R. and Schröter, F. (2001). „Stähle für den Stahlbau – Auswahl und Anwendung in der Praxis", *Stahlbau-Kalender 2001*, S. 545-589.

Scharff, A., Seyffarth, P. and Szieslo, U. (2001). „Mehrfachoptimierung beim Auftragsschweißen hochfester Baustähle", *DVS-Berichte Band 216*, S. 1-6.

Seyffarth, P. and Kassatkin, O. G. (1984). „Rechnerische Bestimmung der prozentualen Gefügezusammensetzung in der Wärmeeinflusszone niedriglegierter Stähle", ZIS-Mitteilungen, Jg. 26, H. 12, S. 1284-1292.

Seyffarth, P. and Scharff, A. (1998). „Möglichkeiten zur Vorauskalkulation von Gütewerten und Prozessdaten", *der praktiker*, Jg. 48, H. 10, S. 388-393.

Ummenhofer, Th., Weich, I. and Nitschke-Pagel, Th. (2005). „Lebens- und Restlebensdauerverlängerung geschweißter Windenergieanlagentürme und anderer Stahlkonstruktionen durch Schweißnahtnachbehandlung", *Stahlbau*, Jg. 74, H.6, S. 412-422.

Wohlfahrt, H. (2002). „Simulation der Vorgänge im Schmelzbad beim Laserstrahlschweißen zur Voraussage von Nahtbildung, Gefüge, Verzug und Schweißeigenspannungen", Bericht AiF 11.583 A/B, TU Braunschweig.