Research Article

Experimental results-based estimation of cooling time during the TIG surfacing of steels performer with and without preheating

Abstract

The paper shortly characterises the structure of the separate areas of the heat affected zone which occurs in the structural steels during welding and surfacing. It presents the methodology of thermal cycles measuring while argon shielded TIG surfacing of steel plates SM400A. Surfacing was conducted in two variants, i.e. without preheating and with preheating before surfacing. Research resulted in the developing of diagrams determining the value of the maximum temperature of the thermal cycle in the specific place of the element being surfaced for the given heat input Q as well as diagrams enabling the determination of cooling time of a padding weld, assuming that maximum temperature of the thermal cycle in the selected point of the component being surfaced is known for the determined heat input Q during TIG surfacing with and without preheating.

Keywords: welding thermal cycle, TIG process, heat input q, preheating, cooling time

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Introduction

During welding, heat supplied by the welding power source (heat source) to a work piece (element subjected to welding) is used primarily to melt the filler metal and to partly melt the base material on the edges of the weld groove as well as to heat the base material areas near the weld. The stirring of the molten filler metal and the base material results in the formation of a weld (during the process of solidification). In turn, in partially melted zones (i.e. areas adjacent to the weld), heated up to high temperatures during welding, the heat affected zone (HAZ) is formed. In welded or surfaced joints made of steels the HAZ area is not homogenous but composed of several zones differing in terms of their morphology. The aforementioned areas include the coarse-grained HAZ (CGHAZ) heated above a temperature of 1150°C, fine-grained HAZ (FGHAZ) heated above temperature A_{C3}, inter critically reheated (within the range of A_{C1}-A_{C3}) coarse-grained HAZ (ICCGHAZ) and the sub critically (i.e. below A_{C1}) reheated coarse-grained HAZ.[1,2] The process of welding or that of multilayer surfacing entails the interaction of successive thermal cycles translating into specific thermal conditions during the cooling of the weld/overlay weld and of the HAZ. The welding of steel having a higher carbon content and containing chemical elements increasing harden ability, is frequently accompanied by the formation of a hard and brittle layer of marten site (e.g. in the HAZ area) requiring the subsequent heat treatment of a welded joint or an element provided with an overlay weld. In cases where, because of technological aspects, the performance of conventional post-weld treatment is limited or impossible, an effective manner enabling the improvement of plastic properties of hardened areas is the application (particularly during repair welding) of temper bead welding. The aforesaid technique makes it possible to reduce the hardness of hardening structures (marten site, upper bainite) presents in the coarse-grained HAZ (CGHAZ) areas of joints or overlay welds, and, consequently, to improve plastic properties of the above-named areas.[3] The process of welding and that of surfacing vary primarily as regards accompanying thermal conditions. For this reason, it is not possible to compare the above-named processes directly. However, the methodology enabling the estimation of cooling time is similar both in terms of welding and surfacing processes. During surfacing, because of various types of joints, the testing procedure is more complicated than that applied in relation to surfacing. The foregoing is primarily related to the problematic fixing of thermocouples in the HAZ areas of welded joints in comparison with HAZ areas of surfaced elements. This paper aims to present the methodology applied to determine cooling time during surfacing performed using the TIG method.

## Material and methodology of research

The tests involved the use of Japanese unalloyed structural steel grade SM400A. The chemical composition of the steel is presented in Table 1. The Polish equivalent of steel SM400A is steel grade S355JR. Thermal cycles were measured during the mechanised argon-shielded TIG surfacing process performed with and without preheating. The welding power source used in the tests was a TIG STAR BC 300 (model YC-300BC1) machine (Panasonic). Before surfacing, the plate made of steel SM400A (on the opposite side than that with the overlay welds) was provided with several non-passes through openings. The above-named openings were provided with Chromel-Alumel thermocouples (having a diameter of 0.25mm) subsequently used in measurements of thermal cycles (Figure 1).

The process of surfacing performed without preheating involved the use of filler metal grade TGS-70NCb (in the form of a wire) having a diameter of 1.2mm. In turn, the process of surfacing performed with preheating involved the use of filler metal grade TGS-56 (wire) having a diameter of 1.2mm. Both wire grades were manufactured by KOBELCO. The chemical compositions of the filler

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metal wires are presented in Table 2 & Table 3. Thermal cycles were measured using a model involving the process of surfacing performed on the surface of a steel plate. The measurements were performed in conditions of overlapping thermal cycles. The 20 mm thick plate made of steel SM400A was provided with six consecutively applied surfaced layers. The principle governing the surfacing of six layers resulted from ASME regulations,[4] under which the obtainment of the desired tempering effect of hard hardening structures requires the making of a minimum of six welded (surfaced) layers. The proper effect of six surfaced layers was also demonstrated by other research works aimed to determine the possibility of the TIG repair welding of manganese-molybdenum-nickel ferric steel SQV2A TIG.[5,6] The surfacing sequence involved the application of six runs in the first layer, five runs in the second layer etc. and, finally, one run in the sixth layer. The course of a thermal cycle was recorded in relation to each run. The schematic diagram of the surfacing process is presented in Figure 1. The related surfacing test variants are presented in Table 4. The adjustment of preheating temperature values was based on welding engineering practice. During the measurements of thermal cycles, signals from the thermocouples were recorded by independent measurement channels of a DA 100-11-1M recording system (YOKOGAWA, Japan) and, afterwards, converted to their digital form using the DARWIN software programme. The plates containing the overlay welds were sampled for specimens subjected to macroscopic metallographic tests. The specimens were cut out in the thermocouple fixing plane, i.e. the plane of the thermocouple which recorded the highest maximum thermal cycle temperature T_{max}, in the first layer of the overlay weld (approximately 1350ºC). The macrostructure of the specimens was revealed through the two-stage etching in Nital and Picral. The surfaces of the metallographic specimens related to various values of heat input Q were used in measurements of the shortest distances between the thermocouple (fixing point) and the fusion line of individual weld runs. The manner of measurement is presented in Figure 2.
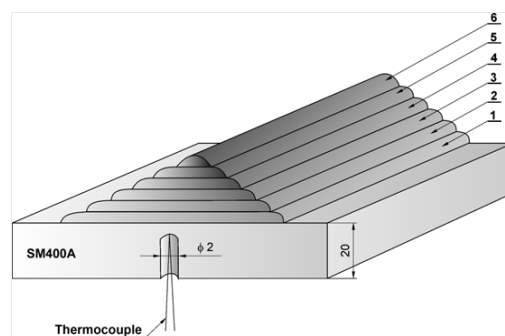
Figure 1 Schematic diagram of the application of overlay welds (in cross-section): 1-6 - successive overlay weld layers.
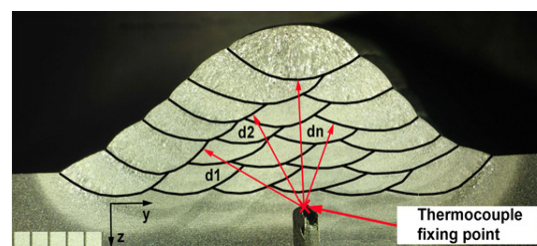
Figure 2 Measurement of the shortest distances d1, d2, … dn between the thermocouple (connection) and the fusion line of individual weld runs

Table 1 Chemical composition of steel SM400A (no. W. 1.0486)

Chemical element content, % by mass						
C	Mn	Si	P	S	Cr	Ni
0.16	1.01	0.16	0.019	0.004	0.033	0.01
Mo	Co	V	Cu	Al$_{solub.}$	Pb	-
0.002	0	0	0.007	0.019	<0.001	-

Table 2 Chemical composition of filler metal wire TGS-70NCb

Chemical element content, % by mass										
C	Mn	Si	P	S	Cr	Ni	Cu	Fe	Nb+Ta	Ti
0.02	3.03	0.21	0.001	0.001	19.85	72.3	<0.01	1.75	2.4	0.3

Table 3 Chemical composition of filler metal wire TGS-56

Chemical element content, % by mass							
C	Mn	Si	P	S	Ni	Mo	Cu
0.09	1.58	0.41	0.007	0.007	0.66	0.52	0.16

Table 4 Scheduled variants of thermal cycle measurements during surfacing

Surfacing without preheating			
Base material	Filler metal	Heat input Q, kJ/cm	Preheating temperature, ºC
		5	20
SM400A	TGS-70NCb	8.5	20
		12	20
Surfacing with preheating			
Base material	Filler metal	Heat input Q, kJ/cm	Preheating temperature, ºC

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Table Continued

Surfacing without preheating			
		5	150
SM400A	TGS-56	8.5	150
		12	150

Research results and discussion

For each heat input Q related sets of maximum thermal cycle temperature T_{max} and cooling times (CT) were obtained. The list of actual values of the experimentally-obtained data concerning the measurements of thermal cycles are presented in Table 5. The cooling time (CT) was determined in the following manner.
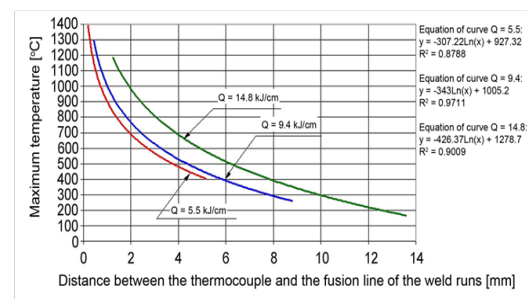
I. When the maximum thermal cycle temperature T_{max} was higher than or equal to 800°C, the time adopted as CT was a cooling time restricted within the temperature range of 800 to 500°C.

II. When the maximum thermal cycle temperature T_{max} was restricted within the temperature range of 800 to 400°C, the time adopted as CT was a cooling time restricted within the temperature range between $T_{max.}$ and 400°C.

III. When maximum thermal cycle temperature T_{max} was equal to or lower than 400°C, the time adopted as CT was a cooling time restricted within the temperature range between T_{max} and $T_{max.}$-100°C.

Table 5 Actual values of heat input Q, ranges of maximum temperature Tmax. and cooling time (CT) obtained in the tests

| Surfacing without preheating			
Heat input Q, kJ/cm	5.5	9.4	14.8
Maximum thermal cycle temperature T_{max}, oC	346÷1365	216÷1295	251÷1336
Cooling time (CT), s	1.5÷4.5	3.0÷8.5	4.0÷10.0
Surfacing with preheating			
Heat input Q, kJ/cm	5.7	9.7	13.8
Maximum thermal cycle temperature T_{max}, oC	383÷1312	399÷1363	356÷1293
Cooling time (CT), s	3.0÷6.5	5.0÷11.0	6.0÷14.5

The experimentally-obtained data were used to develop diagrams demonstrating correlations between the maximum thermal cycle temperatures T_{max} in the function of the distance between the thermocouple and the fusion line of the weld runs. The above-named diagrams are presented in Figure 3 & Figure 4. In welding practice, based on the diagrams presented in Figure 3 & Figure 4 it is possible to forecast the value of the maximum thermal cycle temperature in a specific area of an element subjected to heating, e.g. in the HAZ area, in relation to a heat input Q provided to the area during TIG surfacing performed with and without preheating. The knowledge of the maximum thermal cycle temperature T_{max} makes it possible to forecast the type of HAZ located under the overlay weld, which, in turn, enables the forecasting the type of microstructure in this area. Afterwards, the experimentally-obtained data were used to develop diagrams demonstrating the correlation between cooling time (CT) and the maximum temperature of thermal cycle T_{max} in relation to various values of heat input Q provided during TIG surfacing performed with

and without preheating. The above-named diagrams are presented in Figure 5 & Figure 6. The diagrams presented in Figure 5 & Figure 6 are used to estimate the cooling time of the weld where the maximum temperature of thermal cycle T_{max} in the specific area of the element subjected to surfacing is known. The determination of the cooling time enables the adjustment of the technological parameters of the surfacing process ensuring the obtainment of the most favourable plastic properties of such HAZ areas as CGHAZ, ICCGHAZ and SRCGHAZ.
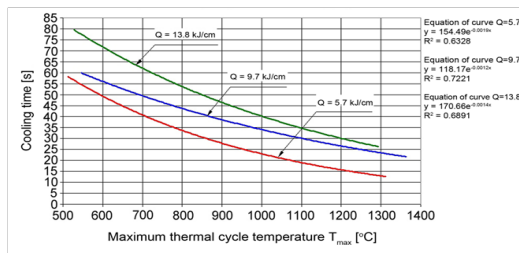

Figure 3 Correlation between the maximum thermal cycle temperature Tmax. in relation to the distance between the thermocouple and the fusion line of the weld runs in relation to various values of heat input Q provided during TIG surfacing performed without preheating
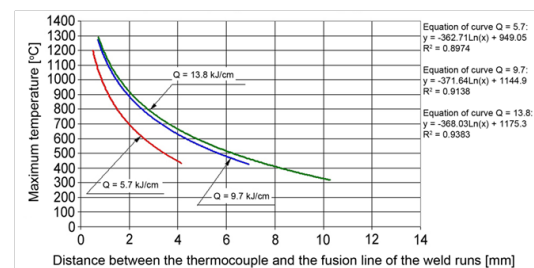
Figure 4 Correlation between the maximum thermal cycle temperature Tmax. in relation to the distance between the thermocouple and the fusion line of the weld runs in relation to various values of heat input Q provided during TIG surfacing performed with preheating
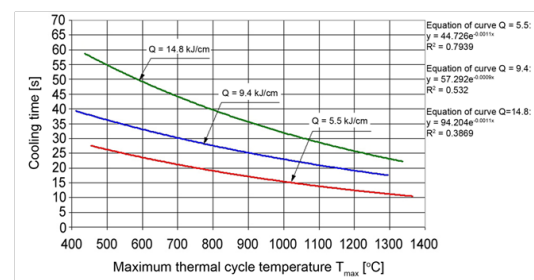
Figure 5 Correlation between cooling time (CT) and the maximum temperature of thermal cycles Tmax. in relation to various values of heat input Q provided during TIG surfacing performed without preheating

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Figure 6 Correlation between cooling time (CT) and the maximum temperature of thermal cycles Tmax. in relation to various values of heat input Q provided during TIG surfacing performed with preheating

Conclusion

The performed experimental tests justified the formulation of the following practical conclusions:

a) The diagrams presented in Figure 3 & Figure 4 enable the identification of the maximum temperature of thermal cycle $T_{max.}$ in the specific area of the element subjected to surfacing in relation to given heat input Q provided during TIG surfacing performed with and without preheating.

b) The diagrams presented in Figure 5 & Figure 6 enable the identification of the cooling time (CT) assuming the knowledge of the maximum temperature of thermal cycle $T_{max.}$ In the specific area of the element subjected to surfacing in relation to given heat input Q provided during TIG surfacing performed with and without preheating.

Acknowledgements

Conflict of interest

Authors declare that there is no conflict of interest.

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