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Crack-free welding without preheating – DI-MC 355T/S355ML

Revision 0, May 2017, 6 pages

Keywords: Preheating, thermomechanical rolling, DI-MC 355T/S355ML, cracks

Efficient processing with Dillinger heavy plates

DI-MC 355 – the S355M/ML of Dillinger – has due to it slender chemical composition very low carbon equivalents. As one of the carbon equivalents (CET) is used to calculate the needed preheating temperature acc. to EN 1011 Method B, the low alloying contents of such thermomechanically rolled plates allow reducing or even completely avoiding the preheating before welding. This offers especially due to the reduced heating and cooling times significant savings in time and cost during fabrication. Thermomechanical rolling enables by that efficient processing in combination with best mechanical properties.

Crack-free – even without preheating

Modified (larger dimensions compared to the standard) Tekken test specimens were produced from 75 und 85 mm thick coupons of the steel grade DI-MC 355T/S355ML to investigate the cold cracking tendency (hydrogen induced cracking) of this thermomechanically rolled steel. This investigation should demonstrate whether the time and cost intensive preheating before welding can be avoided. Additional tests were conducted to intensify the test conditions by using a single SAW weld as the root weld.

The low carbon equivalent and low contents of alloying elements of the base material (DI-MC 355T/S355ML) lead to low hardening in the heat affected zone (HAZ). Due to this no evidence towards hydrogen induced cracking in the HAZ was detected even without preheating before welding.

Theoretical background for hydrogen induced cracking

In the electric arc during the welding process, hydrogen from the surrounding is transformed from the gas state to atomic state and can diffuse in the liquid weld pool and in the adjacent heat affected zone. The microstructure of maximal hardness in the heat affected zone is embrittled by the absorbed hydrogen. This process is extensively described in literature /i/ and can lead to cracks as shown in figure 1.

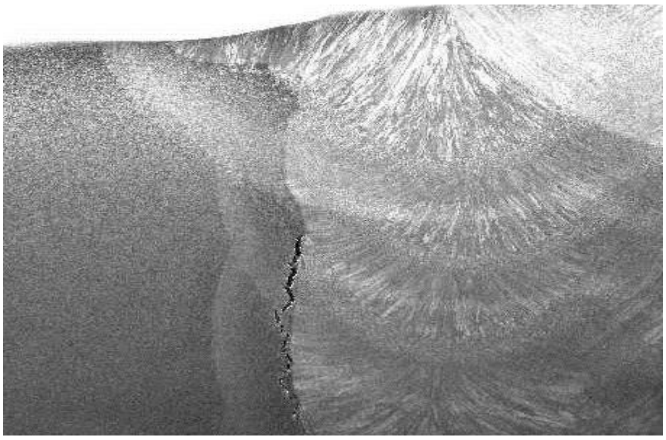

Figure 1: Hydrogen induced cracking in a weld joint

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Influencing factors for hydrogen induced cracking

- Chemical composition of the steel (carbon equivalent)
- Strains due to the heat input during welding
- Hydrogen, that diffuses in the weld joint

The steel producer can only influence the first of these three influencing factors, the chemical composition of the base material. Simplified, the cold cracking risk increases with higher contents of alloying elements. But these alloying elements can for example be necessary to realize high strength of a plate. Due to the high torsional moments that are available at the rolling mills of Dillinger as well as due to special rolling and cooling schedules it is possible to achieve the desired properties with significantly lower alloying elements by refining the grain structure of the steel. The smaller the grains in a plate, the less additional alloying is necessary to adjust the strength properties.

Test welding without preheating

Chemical composition of the base material

1st test plate

Plate thickness 85 mm

C	Si	Mn	P	S	N	Al	Cu	Mo	Ni	Cr	V	Nb	Ti
0.06	0.35	1.56	0.010	0.001	0.004	0.031	0.03	0.02	0.05	0.05	0.001	0.015	0.003

CE (IIW): 0.34
CET: 0.22

2nd test plate

Plate thickness 75 mm

C	Si	Mn	P	S	N	Al	Cu	Mo	Ni	Cr	V	Nb	Ti
0.06	0.34	1.45	0.014	0.001	0.003	0.030	0.05	0.01	0.05	0.04	0.000	0.015	0.001

CE (IIW): 0.32
CET: 0.21

Specimen preparation

To investigate the cold cracking tendency of steel several test procedures and specimen geometries are known /ii/. They can be divided into tests with externally loaded samples (Implant) and self-loaded samples (Tekken, CTS). The two latter can be inquired in the frame of a pre-qualification when ordering acc. to EN 10225 or API RP2Z and are part of our offshore approvals.

For the first investigations Tekken specimen in full thickness (85 mm) with a length of 400 mm were used. This significantly enlarged specimen dimension compared to the standard specimen (200 x 150 x max 50 mm) was necessary to test the automated welding processes with a sufficient test length.

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Figure 2: Preparation of test specimen

Filler metal and weld parameter

First in every test sample a single welding bead (GMAW, SAW 1-Wire) was welded at room temperature with no preheating, as this is the most critical condition for hydrogen induced cracking. An additional weld scenario was tested by first welding a GMAW root weld in the sample, and then, after full cooling down and a waiting time of 48 hours, an additional SAW 1 wire bead as first filler bead was welded.

Furthermore a test specimen with the dimensions 800 x 400 x 75 mm was prepared from a 75 mm plate accordingly to the above described specimen preparation and here the GMAW root weld bead was followed by a SAW 2 wire bead (tandem).

Welding process	Filler metal	kJ/mm
GMAW	EN 758 T46 MM H5	1.3
SAW 1 wire	DIN EN 756 S3Si	2.6
SAW 2 wire	DIN EN 756 S3Si	2.6

Figure 3: GMAW and SAW welding of Tekken test specimen

After welding and a waiting time of 48 hours, the specimens were investigated first by dye penetrant examination to see possible surface cracks. Subsequently, from every test sample 5 macro sections were taken and tested for cracks in a metallographic laboratory.

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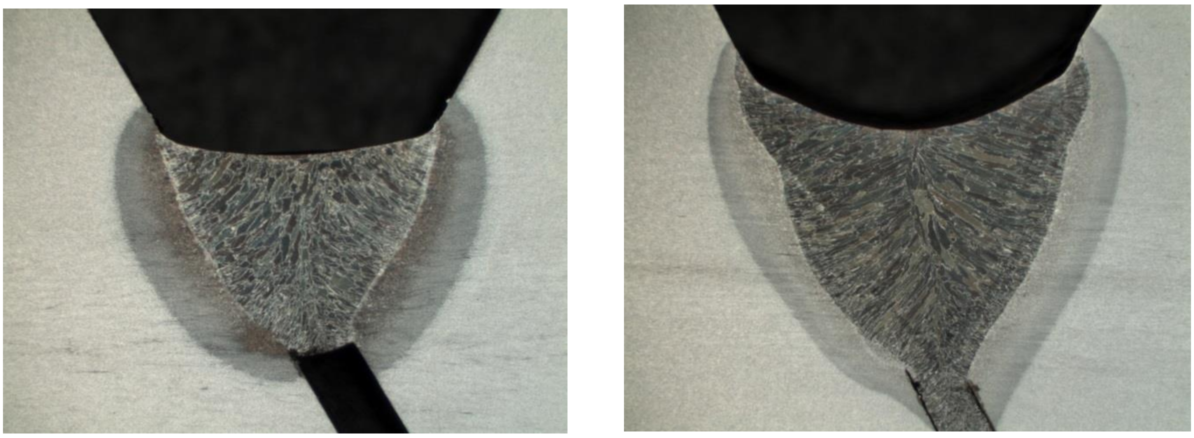

Figure 4: Macro sections of test beads for GMAW and GMAW/SAW 1 wire at 85 mm plate thickness

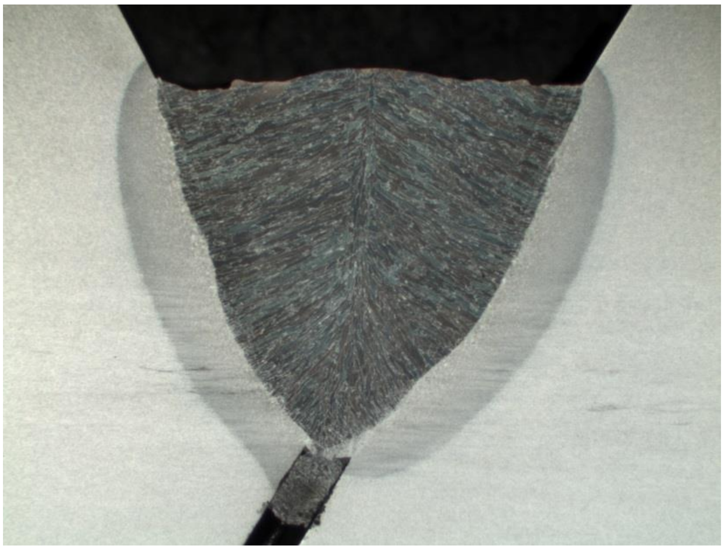

Figure 5: Macro section of 75 mm GMAW/SAW tandem test bead

Test results

- <u>Hydrogen induced cracks</u>

In spite of abandoning the preheating, not a single weld showed evidence of hydrogen induced cracking, as it is demonstrated in figure 1.

Even for the SAW Tandem test bead no indication of hydrogen induced cracking could be observed after 48 hours neither in the dye penetrant examination of the surface nor in the subsequent microscopic investigation of 5 macro sections.

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- Hardness HV10 in the heat affected zone

As expected, due to the lower heat input and the higher cooling speed associated with it, the hardness values of the GMAW weld are circa 50 HV higher than the one of the SAW weld. The limit for maximum hardness in the heat affected zone as demanded in a welding procedure qualification for grades DI-MC 355T/S355ML is 380 HV 10 which is safely fulfilled in both cases. /iii/

GMAW welding 85 mm 1.3 kJ/mm

311	311	309	302	297	309	309	306	304	306

SAW 1 wire welding 85 mm 2.6 kJ/mm

216	221	242	251	256	242	243	249	251	237

Determination of hydrogen content

The hydrogen entry in the weld was identified by a eudiometer in glycerin for the different welding processes and used welding parameters. Therefore a short weld bead was welded on a test sample and afterwards directly put in a closed glass measuring cylinder filled with glycerin. The diffusible hydrogen escapes from the sample, rises upwards and thereby displaces the glycerin. Thus the hydrogen input related to the deposited weld metal can be quantified in the unit HDM ml/100g. /iv/

Figure 6: Diffusible hydrogen escapes from the test bead in the glycerin bath.

After 48 hours waiting time the following hydrogen contents were measured for the respective welding processes.

GMAW	0.9 ml/100g (0.8 ppm)
SAW 1 wire (direct current DC +)	2.0 ml/100g (1.8 ppm)
SAW 1 wire (alternating current AC ≈)	7.4 ml/100g (6.7 ppm)
SAW 2 wire (AC, DC +)	4.8 ml/100g (4.4 ppm)

As expected, GMAW welding leads to the lowest hydrogen input, as in GMAW welding one possible hydrogen source, the welding flux, is lacking. Likewise, as known from other investigation, SAW welding with alternating current leads to higher hydrogen input compared to direct current SAW welding with same welding parameters. /v/

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Revision 0
Dillingen, May 2017
Marketing and Technical Support

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i C. Schwenk, T. Kannengiesser und M.Rethmeier, „Restraint conditions and welding residual stresses in self-restrained cold cracking tests," Trends in Welding Research, Proceedings of the 8th International Conference, pp. 766-773, 2009.

ii Zerstörende Prüfung von Schweißverbindungen an metallischen Werkstoffen - Kaltrissprüfungen für Schweißungen - Lichtbogenschweißprozesse - Teil 2: Selbstbeanspruchende Prüfungen
DIN EN ISO 17642-1:2004-10

iii Anforderung und Qualifizierung von Schweißverfahren für metallische Werkstoffe - Schweißverfahrensprüfung - Teil 1: Lichtbogen- und Gasschweißen von Stählen
DIN EN ISO 15614-1:2012-06

iv Schweißen und verwandte Prozesse - Bestimmung des Wasserstoffgehaltes im Lichtbogenschweißgut
DIN EN ISO 3690:2012

v SVZ Kb 08.03.1993 Bestimmung des Wasserstoffgehalts in UP Einlagen- und Mehrlagen-Schweißverbindungen