68th IIW Annual Assembly– Helsinki, Finland.
Report of Commissions II & IX

June 28th to July 3rd, 2015

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COMMISSION II: "ARC WELDING AND FILLER METALS"

I. SUB-COMMISSION II-A "METALLURGY OF WELD METALS"

Chair: Thomas Kannengiesser (Germany)

II-1933-15 (II-A-299-15; X-1804-15)

An Approach to Assess Residual Stresses in Welded Components

D. Schroepfer, A. Kromm and Th. Kannengiesser

The purpose of the study is to develop an approach for residual stress assessment in high-strength steels S690QL (crane components). The approach is based on the interaction effect between design, welding process parameters and material on the welding stresses.

It was concluded that high heat input, elevated high interpass temperatures and high restraint conditions (joint design, shrinkage restraint) increase the intensity of the tensile residual stress in the heat affected zone (HAZ) of the welded joint.

Regarding the weld metal, the most influencing parameters on residual stress are the transformation temperature of the filler metal, the cooling time $t_{8/5}$ and the welding procedure (number of welding layers) in addition to the heat input and interpass temperature.

II-1955-15 (II-A-301-15)

Ductility-Dip Cracking in the base metal HAZ of nickel base alloys – Correlation of PVR and STF results.

C. Fink, M. Zinke and S. Juettner

The objective of the study is to evaluate the DDC in HAZ of three NiCrFe15 wrought alloy variants by the strain-to-fracture (STF) test using hot cracking criteria and to compare results to those already obtained by programmable-deformation crack (PVR) test. The three nickel-based alloys, Alloy 600H, 600L and 600 differ mainly by their carbon content and the heat treatment cycles they underwent, which result in different grain sizes and amounts of precipitates in the microstructure. Carbon content (wt %) and ASTM grain size are the following: (0.07%, 1.8), (0.003%, 4.4) and (0.065%, 9) for alloys 600H, 600L and 600), respectively.

Results showed that the temperature-strain curve obtained by STF varies with the carbon content and the heat treated condition. Also, the threshold strain (ε_{min}) to cause cracking arises at different ductility-dip temperatures ranges (DTR) for each alloy.

It is concluded that the resistance to the occurrence of hot cracking for the three alloys follows the same ranging order in both tests. The comparison reveals that a wide DTR with a low threshold strain (ε_{min}) in STF test corresponds to a low critical tension speed (v_{cr}, DDC) in PVR test, which representing a high DDC susceptibility in both externally loaded hot cracking tests. Both tests have given a qualitative and reliable ranging of the DDC susceptibility of the alloys. Therefore, the concordance of results allowed to range the resistance to DDC of the studied alloys in the following order: 600 (1st), 600L (2nd) and 600H (3rd).

No information was given neither on the DDC probability in real component welds nor on the transferability between the different cracking criteria.

II-1934-15 (II-A-300-15)

In-situ load analysis in multi-run welding using LTT filler materials

J. Dixneit, A. Kromm, Th. Kannengiesser and J. Gibmeier

The low transformation temperature LTT filler metals have been investigated in restrained multi-pass butt welded joints in high-strength steel S690QL using pulsed-GMAW.

The results show that the contraction of the weld metal in each weld pass occurring upon cooling under the transformation temperature Ms is accompanied by the development of compressive residual stress in the weld metal. Compared to conventional metals, the LTT filler metal acts on the reduction of tensile stresses in the weld joint while also reducing the bending moment and the risk of distortion. The results show the presence of low longitudinal residual stresses on the surface of the joint while the transverse residual stresses are less affected due to restraint conditions. It was conducted that other parameters, namely the heat input and shrinkage must also be controlled to lessen tensile residual stresses in the weld joint and HAZ.

II-1928-15 (II-A-294-15)

Effect of hydrogen on mechanical properties of simulated heat affected zone of a SA508Cl.3 reactor pressure vessel steel grade

M. Rhode, C. Primault, G. Tirand and Th. Kannengiesser

The study deals with ASTM A508 Cl.3 (AFNOR 16MND5) low-alloy carbon manganese steel base metal and its simulated as-quenched coarse-grained HAZ using hydrogen-free and hydrogen-charged tensile specimens.

The results showed that the effect of hydrogen on the mechanical degradation is much more pronounced in the as-quenched HAZ than in the tempered base metal. It has also been shown that the degree of this degradation, which is reflected by a drop of ductility, increases in the following order: base metal BM, bainitic HAZ (B-HAZ), martensitic HAZ (M-HAZ). Hydrogen changes the fracture mechanism from the ductile mode to the brittle mode with the formation of intergranular and quasi-cleavage fracture surface in the prior austenite grain boundaries.

Results show the following losses of ductility from uncharged condition to H_2 charged condition:

- BM : from above 20 to 15% at 3 ml/100 gr of weld metal;
- B-HAZ : from 12% to below 4% at 2 ml/100 gr of weld metal;
- M-HAZ : from 15% to near 0% at 2 ml/100 gr of weld metal.

The untemeperd martensitic HAZ with the highest hardness (> 400 HV) and the strongest tensile strength is the more susceptible to hydrogen-induced cracking (HIC) and ductility loss. This denotes that any joining or welding repair must be done with a good control of heat input to avoid fast cooling and hence a fully martensitic microstructure. This especially applies when using low-energy welding process like TIG on thick material sections.

II-1932-15 (II-A-302-15)

Hydrogen-assisted cold cracking in welded joints of press hardened 22MnB5

O. Schwedler, M. Zinke and S. Juettner

The objective of the study is to determine the diffusible hydrogen in 1.5 mm thick base metal sheet after press hardening and GMAW with CMT (Cold Metal Transfer) process using G3Si wire (AWS A5.18 ER70-S6).

HIC was characterized by the four-point-bend testing method and the results showed the following:

- hydrogen absorption takes place during austenization in press hardening as per the dew point of the furnace and from hydrogen-containing media (water, oil) on the sheet surface.
- increasing diffusible hydrogen promotes the occurrence of HIC at lower stress on the extreme fiber of the welded sample;
- most of cracks propagate along the fusion line;
- acoustic emission is a useful technique for detecting crack initiation
- soaking at 180 °C for 20 mn allows hydrogen effusion from the metal.

II-1956-15 (XII-2236-15)

Development of low hydrogen welding process for gas shielded arc welding

N. Kawabe, T. Maruyama, K. Yamazaki, R. Suzuki

The objective of the study deals with the development of new/modified low-hydrogen gas-shielded arc welding process. The concept is based on the incorporation of a suction nozzle between the contact tip and the shielding nozzle to suck and evacuate a part of the hydrogen-rich shielding gas formed near the wire extension. Thus, the additional nozzle prevents the transfer of the hydrogen near the arc, which allows to reduce the diffusible hydrogen in the molten pool.

Welding tests resulted in the following findings:

- For a rutile-type flux cored wire- 780 MPa with a shielding gas flow rate of 25 l/mn (gas: Ar-20% CO_2), the diffusible hydrogen (DH) content decreases from 2.0 to 0.9 ml/100 g by replacing the conventional process by the new one with an evacuated-gas flow rate of 3 l/mn. This denotes a reduction of more than 50% of DH.
- Other mild steel flux cored wires with a shielding gas flow rate of 25 l/mn (100% CO_2) showed a decrease of DH by 50 % with an evacuated-gas flow rate of 5 l/mn.
- The seamed wire can release more hydrogen, through the seam, than the seamless wire or the solid wire for which le reduction ratio of diffusible hydrogen is lower.
- The evacuation of the partial shielding gas through the suction nozzle does not affect the efficiency of the shielding gas.
- The developed process enables to reduce the minimum preheat temperature to prevent cracking as a consequence of the reduction of diffusible hydrogen.

II-1930-15 (II-A-296-15)

HAZ softening behavior in Nb, Ti and Nb-bearing quenched and tempered high strength steels

L. Zhang and Th. Kannengiesser

The study aims to investigate the effect of the heat input on HAZ softening in three high-strength Nb, Ti, V+Ti microalloyed S690QL steels for V-groove single-pass butt joints welded with a matching filler metal by means of an automated GMAW process. Tests were conducted with three levels of heat input. The results obtained conclude the following:

- The softened zone is located at approximately 3 mm from the fusion line and its width increases with increasing heat input. The degree of the softening depends first on the alloy chemistry and then on the heat input:
    - Ti-steel undergoes more softening than others with a soften width reaching 1.8 mm at high heat input, namely twice larger than that in the other ones, with a minimal hardness of 203 HV10. Therefore, this softening degree did not significantly affect the tensile strength. Besides, an elongation to fracture of 10% was recorded.
    - the high softening degree experienced by Ti-steel is due to its low hardenability explained by the high fraction of coarse ferrite phase and coarser carbides along the grain boundaries.
    - Nb-steel has the greatest resistance to softening while Ti+V steel suffered moderate softening. In addition, the tensile properties remained preserved for both.
- Tensile test shows that the failure is mostly located in:
    - the base metal for Nb and V+Ti- steels.
    - the soften HAZ of Ti-steel welded with medium and high heat input.
    - the base metal of Ti-steel welded with low heat input.

II-1931-15 (II-A-297-15)

Properties and Optimization of Dissimilar Aluminum Steel CMT Welds

E. Unel and E. Taban

The study deals with the characterization of dissimilar cold metal transfer welded lap joint between 1.0 mm low Mg aluminum alloy EN 5754-H111 to 0.75 mm DX54D+Z galvanized steel. This is done with a modified AlSi3Mg filler metal alloy under straight argon shielding gas. It is noted that this low heat input process only results in melting of the aluminum side whereas the steel remains in the solid state.

It was found that the optimal welding parameters for the joint integrity consist of the combination of a wire feed speed WFS of 4-5 m/mn, a welding speed of 8-10 mm/s and a deviation distance of 0-1 mm. Besides, the increase of the heat input results in increasing the thickness of the brittle intermetallic compound layer (IMC) between parent materials, which lowers the joint strength. Two main compounds were revealed: Fe_2Al_5 near the galvanized steel and Fe_3Al on the aluminum side. Regarding the effect of heat input, it was concluded the following:

- a heat input of 0.6 kJ/cm leads to a welded joint whose the strength is 80% of that of Al-base metal;
- a heat input of 0.8 kJ/cm leads to an IMC layer of less than 5 µm;
- higher heat input promotes thicker IMC layers (> 10 µm), which drastically affects the joint integrity.

II. Sub-commission II-C "Testing and Measurement of Weld Metal"

Chair: Zhuyao Zhang (United Kingdom)

II-1923-15 (II-C-485-15)

Protective atmosphere influence on structure transformation and service properties of Cr-Ni-Si steel by MIG/MAG pad welding

Y. Lopukhov, R. Abdurakhmanov, R. Gabdyssalyk

The study deals with the influence of different shielding gas compositions (Ar, CO_2, 30% N_2- 70% CO_2, 50% N_2- 50% CO_2, 70% N_2- 30 %CO_2, N_2) on the microstructure formation and the wear resistance of a MIG/MAG weld metal deposited by a metal cored wire 10Cr17Ni8Si5Mn2Ti on the carbon steel plate 20 GOST 1050-88 (~ ASTM A1020).

The results showed the formation of a martensite layer zone in the base metal. The depth and the hardness of the latter are the lowest when welding with 70% N_2- 30% CO_2 and 50% N_2- 50% CO_2 gas mixtures.

The transition zone with the base metal is marked by an important increase in hardness, reaching 44 and 42 RC at 1 mm from the base metal when welding with rich-CO_2 gases: CO_2, 30% N_2- 70% CO_2 respectively. However, 70 %N_2- 30% CO_2 and 50% N_2- 50% CO_2 gas mixtures produced lower and more uniform distribution of hardness in this transition zone as well as through the rest (height) of the weld pad with an average of 32-36 RC. This decrease in hardness is associated with the decrease of the delta-ferrite content as the nitrogen content increases in the shielding gas.

Due to the effect of dilution, the ferrite content decreases from the 1st layer to the last (3rd) layer irrespective of the type of shielding gas but N_2-containing gases result in lower levels of ferrite. Moreover, the 70% N_2- 30% CO_2 gas produces the lowest ferrite content, namely 28%, compared to the highest ferrite level of 67% obtained with 100% Ar in the 3rd layer of the weld pad. Pad welded under nitrogen-bearing gases lead to the precipitation of high quantity of nitrides and Ti-carbonitrides that serve as nucleation sites for crystallization of the austenite matrix in the weld metal.

The austenitic weld pads enriched with nitrogen are less likely to the precipitation of the brittle intermetallic sigma phase at high temperatures. The use of 50% N_2-50% CO_2 and 70% N_2- 30% CO_2 allow to dope the weld pad with a nitrogen content of 0.12 to 0.16%, which in turn increases the scoring resistance and erosion hardness by 1.6 and 1.7 times respectively. This is due to the hardening effect of the austenitic matrix by the precipitation of nitrides and carbonitrides.

II-1947-15 (II-C-476-15)

Choice of Welding Consumable and Procedure Qualification for Welding of 304HCu Austenitic Stainless Steel Boiler Tubes for Indian Advanced Ultra Super Critical Power Plant

G. Srinivasan, H.C. Dey, A.K. Bhaduri, S.K. Albert and T. Jayakumar

The main purpose of the study is to choose the appropriate filler metal and develop WPQ as per ASME-IX for TIG welding of similar stainless steel 304HCu/304HCu and dissimilar 304HC SS/ Inconel Alloy 617 weld joints. These type of joints are used for assembling boiler tubes in power plants. Welding procedures consist of welding the similar joint of 304HCu SS with three different filler metals: ER304HCu, ER625 and ER617. On the other hand, the dissimilar joint is welded with ER617 filler metal. Tests were done in 1G position with a single-V groove (65-70°) with a heat input of 0.9- 1.5 kJ/mm.

It was concluded that all welded joints meet the acceptance criteria of ASME-IX Class 1 requirements. Furthermore, the similar weld joint 304HCu SS welded with the matching FM ER304HCu exhibits the lowest micro hardness profile through the weld metal, the fusion line and HAZ. Also, the same joint has the highest ductility (A: 30- 32%) in the temperature range of 550- 700 °C.

It was also shown that the similar joint 304HCu welded with the matching filler metal ER304HCu and the dissimilar welded joint 304HCu/617 Alloy have higher creep life than the base metal 304HCu at 650 °C and under 260 MPa. However, the similar joint 304HCu welded with ER625 has lower creep strength than the base metal and the failure occurred in HAZ. Regarding the dissimilar joint 304HCu/617 Alloy, the failure occurred in HAZ on the 304HCu side. To conclude, the matching filler metal ER304HCu and ER617 were chosen for the welding procedure of the similar 304HCu/304HCu and the dissimilar 304HC SS/ Alloy 617 joints respectively.

II-1949-15 (II-C-478-15, IX-C-1050-15)

Effect of Annealing Time on the Mechanical Properties of P91 Flux Cored Wire Weld Metal

S. Baumgartner, A. Holy, M. Schuler, R. Schnitzer, N. Enzinger

As per standards AWS A5.29 and EN ISO 17634, Ni content of filler metals is 1.0 wt% max and (Ni+Mn) is 1.5% max. In AWS A5.36-2012, the Mn+Ni content is limited to 1.4 wt% max. Such a high content of these austenite-forming elements may lower the A_{C1} transformation temperature up to 770 °C.

In order to be able to perform a PWHT without any risk of exceeding A_{C1} to avoid austenite reformation, the Mn+Ni content must be limited to below 1.0 wt% since this content limit leads to A_{C1} temperature of nearly 800 °C. It must be noted that the PWHT temperature is also limited by the annealing temperature of the base metal.

Nickel enhances the impact energy of the weld metal at room temperature. The specifications AWS A.36 and EN ISO 17634-A require an impact energy of 27 and 47 J respectively at room temperature for the all-weld metal P91 flux cored wire. Thus, it results that nickel content can be reduced to fulfill the AWS requirement but not that of EN ISO 17634-A standard. In addition, as the temperature and time act synergistically in PWHT, the authors of this study have instead investigated the effect of the PWHT holding time at a constant temperature, namely 760°C, on the impact properties of the weld metal.

The obtained results show the following:

- The holding time increases remarkably the impact energy at room temperature (CVN-RT). Indeed, a holding times of 1, 4 and 12 h give rise to a CVN-RT of 30, 54 and 70 J respectively. AWS and EN ISO requirements are therefore fulfilled depending on the holding time.
- Increasing holding time from 4 to 12 h results in a slight decrease of tensile properties at room and high temperatures.
- The hardness on the cap layer droops from 394 HV10 in the as-welded condition to 236, 220 and then to 210 with holding times of 1, 4 and 12 h respectively.
- The weld metal have a martensitic-bainitic microstructure without precipitation in the as-welded condition. However, the PWHT results in carbides precipitation at grain boundaries in tempered martensite.
- Matcal Simulations emphasize the effect of precipitates coarsening as a result of longer holding times.

II-1951-15 (II-C-479-15)

Monitoring the Quality of Titanium Alloy Welds

M. F. Gittos

The study deals with the quality control inspection of titanium welds by mechanical testing and Eddy Current. This aims to assess the effectiveness of the quality of shielding gases. The characterization concerns commercially pure titanium (CP) and titanium alloy Ti6Al4V (Grade 5) TIG welded under pure argon shielding gas and argon contaminated by 0.3%, 0.6% and 1.5% of air.

The results of tensile testing show that the strength and the hardness of the weld metal increase significantly while the ductility decreases with increasing the contamination degree in the shielding gas. This is due mainly to interstitial elements (O_2, C and N_2) pickup in the weld metal that results in different coloration degrees of the weld surface. For that, the following formula were used to correlate the relative effect of interstitial elements, grouped under the term “oxygen equivalent’’, to weld metal properties:

- O_{Eqv}= O + 2.N + (2/3).C, for CP grades.
- O_{Eqv}= C + N + 2.C, for Ti6Al4V alloy

It has been concluded that Eddy current testing method, based on the determination of electric conductivity on the surface, is useful and reliable for only identifying high levels of contamination for CP weld metals. However, it was found that the hardness test is more sensitive to the contamination than Eddy current method regarding Ti6Al4V alloy.

III. Sub-Commission II-E “Standardization"

Chair: David Fink (USA)

II-1939-15 (II-E-689-15)

Standards Update- 2015 Update on Standards for Welding Consumables under Review

D. Fink

II-1940-15 (II-E-684a-15)

Matrix Filler Metal Classification

D. Kotecki

The presentation was about information on current standards and latest published editions for different types of welding consumables.

II-1941-15 (II-E-685a-15)

Fourth Round Robin Report – Trace Elements in Cr-Mo-V Steel Weld Metal

D. Kotecki.

The study concerns the measurements reproducibility of (Bi + Pb) content, at the level close to 1.5 ppm (proposed reject/accept criterion for reheat cracking factor, without the effect of Sb) in three 2-¼ Cr-1Mo-1V submerged arc groove welds. The three welds were analyzed by 9 nine laboratories participating to this round robin analysis. Among the latter, five laboratories used Inductively-Coupled Plasma Mass Spectrometry (ICP-MS), two used Glow Discharge-Mass Spectrometry (GD-MS), one used Atomic Absorption (AA) and one used Inductively-Coupled Optical Emission Spectrometry (ICP-OES).

Based on the interlaboratory averages and standard deviations, the methods of analysis ICP-MS and GD-MS are the most reliable ones for reproducible measurements of Bi and Pb at levels of 1ppm or less. However, the method ICP-OES did not detect these trace elements at low levels in the three welds. For the method AA, further tests should be done to establish its validity, especially for Pb analysis.

II-1942-15 (IIE-686a-15)

Round Robin analysis of fluxes

D. Kotecki

This study deals with an interlaboratory comparison, called round robin test, regarding the analysis of five fluxes for SAW from different manufacturers. The chemical analysis of each flux was carried out by twelve laboratories. The analysis of the results is based on the calculation of the interlaboratory average content, the standard deviation and the ratio average/deviation standard for each constituent in the flux.

The classification of fluxes based on the chemical composition is given by the standard ISO 14174:2122 (Fluxes for submerged arc welding and electroslag welding).

The results showed that the analysis of major constituents of fluxes is reproducible. However, it was find that one analysis could be assigned more than one classification according to ISO 14174:2122.

This classification of fluxes according to the chemical composition as given by this standard must be reviewed in order to get only one classification for each analyzed flux.

IV. Commission Joint meeting C-II, C-IX-C, C-XI

Subject: **Welding of creep resistant steels**

Chair C-II: Gerhard Posch (Austria)
Chair C-XI: Teresa Melfi (USA)
Chair C-IX C: Peter Mayr (Germany)

IX-C-1059-15

Round Robin on Phase Transformation Temperatures

A. Nitsche, P. Mayr

The aim of the study is to measure the phase transformation temperatures Ac_1, Ac_3, M_s and M_f of P91 martensitic steel ASTM A335. The study consists also in evaluating the possible scattering of the measured values par twelve participants who took part in this work.

It has been found that, although the heating and cooling rates increase scattering of the results, the determination of the temperatures representing the onset of phase transformation, namely Ac_1 and Ms, tends to be accurate and reproducible. However, the determination of the temperatures representing the completion of phase transformation, Ac_3 and M_f seems to be imprecise and shows wider scattering. This could be due to the effect of different test conditions (heating methods, lack of complete heating, delayed thermal expansion, etc.).

IX-C-1057-15

Thermal stability, phase transformation characteristics and thermal properties of T91 steel and welding consumables

R. Subramanian, J. Balakrishnan, H. Tripathy, S. Murugesan, S. Saibaba, S.K. Albert, A.K. Bhaduri

The study aims to characterize the phase stability and transformation temperatures of T91 ferritic steel and its matching consumables. The investigation was carried out using differential scanning calorimetry DSC and dilatometry. Welding consumables consist of three basic electrodes E9016-B9 with different (Ni+Mn) contents and an equivalent filler metal ER90S-B9 for GTAW.

From the study results, it has mainly been confirmed the following:

- the transformation temperatures Ac_1 and Ac_3 increase, but non-linearly, with increasing the heating rate. Ac_3 is more sensitive to the heating rate, thus broadening the intercritical zone Ac_1-Ac_3 for higher heating rates.
- for the same (Cr+Mo) content, the Ac_1 and Ac_3 temperatures decrease consistently with increasing (Ni+Mn) content. Moreover, the activation energy necessary for austenite transformation decreases with increasing heating rate.
- DSC provides comparable and more precise measurements for transformation temperatures.
- dilatometry determines the transformation points, Ac_1, Ac_1, M_s and M_f, less accurately from dilatometric curves. Also, this method does not depict well the Curie temperature Tc due to the small magnitude of $\Delta l/l_0$ associated with the transformation of $alpha_{ferromagnetic}$ to $alpha_{paramagnetic}$.

XI-1131-15

Microstructure, structural stability and properties of T24 steel welded joints

Martin Sondel, Jaroslav Koukal, Drahomir Schwarz

The study deals with the effect of PWHT on the structural stability of a secondary hardening low-alloyed steel T24 welded joint (7CrMoVTiB10-10) for membrane walls in power plants.

As the steel is prone to the secondary hardening, a low- temperature PWHT within the hardening temperature range of 450-550 °C has initially been suggested. However, it has been concluded that these low temperatures are not sufficient to produce a stable and reliable welded joint. In fact, it has been proven that a high interpass temperature of 500 °C results in a secondary hardening that causes a drop in ductility of the weld metal. This represents the same effect occurring in as-welded joints at working temperatures of the boiler. To overcome that, a high temperature PWHT at 740 °C has also been considered.

From the different PWHT regimes experimented for this steel welded with Bohler Union I P24 filler metal and an interpass temperature of 180 °C, the following was concluded:

- Low temperature PWHT at 460 and 530 °C, although it is accompanied by an insufficient diffusion rate for the growth of precipitates, a maximum hardening was shown in:
  - the coarse-grained HAZ (CGHAZ):
    - after PWHT at 530 °C/10 h carried out after welding (as welded-joint) with a resulting hardness of 442 HV1;
    - after a primary PWHT at 460 °C/48 h followed by a second PWHT at 530 °C/1 h, with a resulting hardness of 444 HV1;
  - the weld metal but with less extent compared to CGHAZ due to the tempering effect of the multipass welding:
    - 365 HV1 after PWHT at 530 °C/10 h carried out after welding;
    - 375 HV1 after a primary PWHT at 460 °C/8h followed by a second PWHT at 530 °C /1 h.
- The primary PWHT AT 460 °C/48 h shortens the hardening time of the second PWHT at 530 °C and leads to the formation of further M_3C carbides (M: Fe, Cr, Mn).
- The hardness remains relatively high in both weld metal (340 HV1) and CGHAZ(350 HV1) even after longer holding times (1500 h) of PWHT at 530 °C performed either on the as-welded joint or after a primary PWHT 460 °C/48h.
- The secondary hardening affects strongly the impact strength of the welded joint particularly in CGHAZ. Values of 18 and 4.3 J were recorded in this critical region respectively in as-welded condition and after PWHT 540 °C/10 h.
- A high temperature PWHT at 740 °C/1h performed directly after welding results in a satisfactory level of impact energy in CGHAZ and FGHAZ. For CGHAZ, an energy of 62 J was recorded as compared with 4.3 J for PWHT 540 °C /10h.

It has been concluded that lower temperatures PWHT are not recommended for such secondary hardening low-alloyed steels since they may lead to failure damages like hydrogen-assisted cold cracking (HACC) and stress corrosion cracking (SCC).

V. Sub-Commission IX-L: Low alloyed steel welds

Chair: Prof Norbert Enzinger (Austria)

IX-2521-15

Research of Liquid Metal Embrittlement in Resistance Spot Welding of New High-manganese-content Steels

J. Barthelmie, A. Schram and V. Wesling

The study investigated the phenomenon of Liquid Metal Embrittlement (LME) in 1.5 mm thick mixed joints of high manganese austenitic steel (15% Mn) and micro-alloyed fine-grained steel HX340LAD. Tests were carried out on zinc-coated surfaces and on surfaces without zinc coating for both materials. The integration of FeMn steels in the automotive engineering is due to its high impact strength, high strength besides their good formability.

The investigation showed that no cracking occur when both sheets, FeMn and HX340LAD, are non-galvanized. However, some LME cracks appeared when only the HX340LAD sheet is galvanized. This occurs when the molten zinc penetrates by diffusion along the grain boundaries into the FeMn side. These LME cracks occur in the edge area of the joint.

The heat input reduce the residual stresses, which in turn reduce also he LME sensitivity. Also, the crack length decreases with increasing the electrode force and the diameter of the electrode cap.

High temperatures tensile test revealed the presence of cracks on galvanized FeMn from 450 °C, which is above the melting temperature of zinc. The values of tensile strength in galvanized and non-galvanized specimens are roughly comparable up to temperatures of 400 °C. Above this threshold and up to 600 °C, the tensile strength of galvanized specimens is 50 MPa lower than that of non-galvanized specimens.

IX-2515-15

Blast Resistance of High Strength Structural Steel Welds

Th. E. Falkenreck and Th. Boellinghaus

The study investigated the ballistic properties of welded joints of a high strength QT fine-grained steel (1100 MPa-Ys), 7 and 10 mm thick. The welded joint consists of an angled T-joint composed of a fillet weld and a single-bevel weld. Welding was carried out by manual MAG single layer welding with an undermatchnig ferritic filler metal, EN ISO 16834-A G 62 5 M Mn3Ni1Mo (AWS A5.28 ER90S-G) using different heat inputs. The welded joint was impacted by blasting at high strain rates to investigate its behavior under high impact conditions.

It was found that the decrease of the cooling rate causes the weld joint to endure larger displacements or deformations prior to fracture. The displacement is measured by the movement of the horizontal plate of the fixed welded assembly from its initial position to that reached after blast testing. Higher displacements are attributed to a delayed crack initiation in the weld joint.

Hardness measurements revealed that the base material was work hardened after blasting test. Indeed, the degree of this hardening was correlated to the displacement amplitude: higher displacements cause the base metal to work-harden at large distances, up to 30 mm, from the weld joint.

Further, it was shown that lower cooling rates result in lower hardness gradient from the weld metal towards the HAZ, which changes the fracture mode of the joint and thus increases its impact strength.

IX-2522-15 (IX-L-1143-15)

Quantitative Evaluation of Nucleation Potency of Ti-containing Inclusions for Acicular Ferrite

Kangmyung SEO, Young-Min KIM, Hee Jin KIM, Changhee LEE

The study deals with the nucleation potency of different inclusions on the nucleation and the formation of acicular ferrite (AF) microstructures in Ti-containing weld metals. For that, five types of bainitic welds were investigated. The latter have the same analysis with a constant oxygen content (330-366 ppm) but different Ti levels, from 0.002 to 0.091 wt.%. Welding was carried out with a heat input of 25 kJ/cm using ER100S as filler wire with Ar + 20% CO_2 shielding gas.

It was concluded that the fraction of acicular ferrite (AF) in the microstructure (bainite-ferrite) tends to increase according to the increase of the titanium content, which in turn leads to an increase in the number of inclusions. The lower and the higher proportions of AF are related to the welds at 0.023 and 0.072 wt.%Ti respectively. Metal inclusion analysis showed that inclusions have comparable average size (0.42- 0.48 µm) and area density (1.55- $1.71.10^4$ no./ mm^2), which could be due to the constant amount of oxygen and sulphur in the weld metals.

The increase of titanium content in the weld results in increasing titanium and decreasing Mn and Si in the composition of metal inclusions. In fact, inclusions consist mainly of Mn-silicate (0.02% Ti) Mn-silicate and (Mn, Ti) spinel oxide (0.02- 0.04% Ti), Ti_2O_3 (0.07- 0.09% Ti)

It was found that not all inclusions can act as nucleation sites for acicular ferrite. Indeed, the nucleation probability tends to increase with the inclusions size. Following the results, it appears that the 100% of nucleation probability corresponds to inclusions larger than 0.85 µm in any weld metal. However, it is apparent that the weld metal with 0.072% Ti exhibits the higher tendency of nucleation since it starts to approach this maximum probability when forming inclusions of only 0.45 µm. With this inclusion size, the nucleation probability in the other welds is only of 40- 60%.

Furthermore, the effect of Ti content on the nucleation probability with an inclusion size of 0.45 µm was analyzed. In fact, it was shown that this maximum probability reached with a titanium content of 0.07% Ti corresponds to the formation of Ti_2O_3 inclusions. Further additions of titanium leads to decreasing the maximum nucleation probability for this inclusion size.

IX-2518-15

Austenite grain growth simulation considered Solute-drag effect

FUJIYAMA Naoto, NISHIBATA Toshinobu, SEKI Akira, HIRATA Hiroyuki, OGAWA Kazuhiro

The study aims to predict the solute-drag effect in low carbon steels in multi-solute elements. Solute-drag effect reduces the grain boundary mobility and thus controls the austenite grain growth upon heating.

It was found that the grain growth simulation highlights the fact that the calculated size of the austenite grains at high temperature is smaller and corresponds to the experimental measure when the solute-drag effect is taken into account. The solute-drag effect increases with increasing the number of solute elements in the steel composition. In addition, it was shown that the combination of both effects of solute-drag and pinning, eg. with TiN precipitates, decreases further the austenite grain size and the calculated size matches also the experimental measure.

VI. Sub-Commission IX-H: Stainless steels and nickel alloys

Chair: Dr Elin Westin (Austria)

IX-2527-15 (IX-H-807-15)

Effect of nitrogen on root weld properties of heavy-walled duplex pipe

A.M. Sales, E.M. Westin, P. Colegrove

The objective of the study is to elucidate the effect of nitrogen in backing gas in multi-pass GTAW of 23 mm wall-thick pipe of duplex stainless steel grade UNS S31803/ UNS S32205 (EN 1.4462). The backing gas was varied from 100% argon to 100% nitrogen. The base metal is welded with a matching filler metal ER2209 under the following couples of gases (shielding gas/ backing gas): (100% Ar)/ (100% Ar), (Ar+2% N_2)/ (100% Ar), (Ar+ 2% N_2)/ (Ar+ 2% N_2), (Ar+ 2% N_2)/ (Ar+ 10% N_2), (Ar+ 2% N_2)/ (Ar+ 20% N_2), (Ar+ 2% N_2) / (N_2).

The following findings were concluded:

- the analyzed nitrogen in the root of the weld metal increases with increasing nitrogen in the backing gas before reaching a solubility limit of 0.20% with the backing gas Ar+10% N_2 . In fact, the different N_2 contents were verified with the above-mentioned backing gases: 0.11% N_2 (100% Ar), 0.17% N_2 (Ar+2% N_2), 0.21% N_2 (Ar+10% N_2), 0.20% N_2 (Ar+20% N_2), 0.21% N_2 (N_2).
- the delta-ferrite content decreases in the weld metal with the enrichment of the backing gas in nitrogen. The highest and the lowest ferrite levels in the root weld metal, namely 46% and 25%, were recorded when using pure argon and Ar+20% N_2 respectively as backing gases.
- the impact toughness showed that the highest and the lowest levels of impact strength were recorded with the backing gases 100% Ar and Ar+10% N_2 respectively at -46 °C, and with 100% N_2 and 100% Ar respectively at -65 °C.
- Nitrogen did not have an effect on hardness of the weld metal nor on the transverse tensile of the welded joint.
- the weld metal suffered from a localized corrosion when using pure argon as a backing gas. Pitting resistance showed a loss of 25.2 gr/m^2 compared with 1.70 g/m^2 when replacing pure argon backing gas by Ar+2% N_2. The nitrogen in the backing gas has a significant influence in increasing the pitting resistance. However, as per ASTM A923, the maximum allowed corrosion rate is 1.00 g/m^2. This supposes that a minimum of 10% N_2 in the backing gas (Ar-N_2) is required to pass this corrosion test.

IIW IX-2526-15

Slag island characteristics and weld penetration in very low sulphur stabilized ferritic stainless steel EN 1.4509

S. Anttila, V. Lauhikari, H.-P. Heikkinen, D. Porter

The study deals with the development and the composition of slag islands formed on weld beads in very low-sulphur heats of stabilized (Nb-Ti) ferritic stainless steel EN 1.4509 (UNS S43940). The welding tests were performed by a mechanized autogenous TIG welding for full and partial welds. Slagging phenomenon was investigated only on the face side of the different welds.

In that context, it has already been shown that slagging is connected to penetration since both phenomena are sensitive to the weld pool behavior. The results of this investigation highlighted the followings:

- the low sulphur content, varying from 4 to 23 ppm max, does not promote the inward fluid flow of the weld pool and has thus no significant influence on penetration.
- calcium and, to a lesser extent, titanium, have a significant adverse effect on penetration since these elements eliminate free-oxygen and sulphur for forming stable oxides (TiO_2, CaO) and sulphides (CaS). This results in disturbing the fluid flow of the weld pool while producing slag islands.
- Increasing heat input, for the same content of calcium, results in improving penetration.
- Silicon has a slightly detrimental effect on penetration.

Regarding slagging, two variant of slags were revealed, namely:

- ignition slag in forms of semi-continuous island occurring after the arc strike. It is located at the centre of the weld pool and is promoted by aluminum. This slag is mostly composed of solid Al_2O_3 rafts and Al_2O_3- rich Al_2O_3-CaO.
- slag spots with varying size-round particles occurring near the fusion boundary. These are promoted by calcium and titanium and mainly comprised of solid TiO_2-rich TiO_2-CaO-Al_2O_3 with less than 40% Al_2O_3.

IX-2528-15 (IX-H-808-15)

Influence of Multiple Thermal Cycles on Microstructure of Heat Affected Zone in TIG Welded Super Duplex Stainless Steel

Vahid A Hosseini, M. Asunción Valiente Bermejo, Johannes Gårdstam, Kjell Hurtig and Leif Karlsson

The study aims to show the influence of heat Input, namely 0.37 and 0.87 kJ/mm, and multiple thermal cycles on the microstructure of HAZ in an autogenously TIG welded SDSS 2507. Results showed the occurrence of the following distinct regions in HAZ following the peak temperature:

- fusion boundary zone corresponding to the formation of nitrides band closer to the fusion boundary line within the temperature range of 1250-1350 °C. Low heat input results in high cooling rates during austenite formation. This gives less time to nitrogen diffusion in austenite, which then promotes precipitation.
- precipitation free-zone, located at 1-2 mm from the fusion boundary, corresponding to the temperature range of 1050-1250 °C.
- Sigma phase precipitation zone, from 3 mm of the fusion line, corresponding to the temperature range of 828-1028 °C.

The multiple reheating cycles were found to have more effect than slower cooling on promoting precipitation of sigma phase.

The ferrite measurements showed that the ferrite content in HAZ is not affected by the number of passes in low heat input welding. However, a slight decrease of the ferrite content was revealed from the second pass at 1- 2 mm from the fusion line in samples welded with high heat input. This is caused by lower cooling rates, giving rise to more time for austenite formation.

IX-2529-15

Obtaining BTR of Varestraint test using high-speed camera and two-color thermometry

Daisuke ABE, Yu MURAKAMI, Fumio MATSUZAKA, Takaaki MATSUOKA and Hiroto YAMAOKA

The study deals with proposing a new test method to measure accurately and directly the brittleness temperature range (BTR) in-situ observation by a high-speed camera and two- color thermometry system.

In this original method, the critical strain is calculated by the time from bend start in Varestraint test and "time-strain" curve pre-measured by strain gauge. Regarding the temperature, it is calculated by two-color thermometry using in-situ observation images. For the conventional method, the strain is calculated by the radius of the bending block and the specimen thickness. However, the temperature is calculated by the crack distance from the fusion line and the pre-measured cooling rate.

The relevance of this new method was initially tested by measuring the temperature of the molten pool on a pure nickel plate melted by TIG arc. The measured melting point was 1455 °C, which reflects the melting temperature of this metal.

The BTR is calculated by the target crack which is the maximum length crack. The temperature is then continuously measured by two-color thermometry system from the crack initiation until reaching its maximum with increasing strain and decreasing temperature.

X-2530-15

Ductility-dip Cracking Susceptibility in Dissimilar Welds of Alloy 690 Filler Metal and Low Alloy Steel and Development of the Evaluation method

Kota Kadoi, Makoto Hiraoka, Kenji Shinozaki, Motomichi Yamamoto, Takeshi Obana

The main aim of this study is to show the effect of dilution ratio on the ductility dip-cracking DDC susceptibility of a dissimilar overlay welds of 690 filler metal, ERNiCrFe-7 and ERNiCrFe-13, deposited on a low alloy steel. A new evaluation method was developed to measure the critical strain for the crack initiation during the DDC test. The latter consists of a high temperature tensile test coupled with in-situ observation using a high-speed camera.

The study highlighted the following:

- the critical strain for the crack initiation of ERNiCrFe-13 is higher than that of ERNiCrFe-7 in the temperature range of 700- 1050 °C. A critical strain of 1.3% at 900 °C versus 4.0% at 943 °C were showen for ERNiCrFe-13 and ERNiCrFe-7 respectively.
- the minimum strain and the temperature corresponding to crack initiation decrease with increasing the dilution rate. The ductility-dip temperature range DTR also increases as the dilution rate increases. It is to be noted that the filler metal ERNiCrFe-13 was developed by adding 4.0% Mo and 2.5% Nb to get a better DDC resistance than that of the former filler metal ERNiCrFe-7.
- the minimum critical strain increases with the tortuous ratio, which characterizes the geometry of the grain boundary and its orientation against the tensile direction. This trend was confirmed by the microstructure features of the undiluted weld metal of both filler metals and the weld overlays diluted by the base material. For that purpose, it was established that the increase of the dilution rate results in increasing the tortuous ratio and hence the DDC susceptibility.
- the minimum critical strain was correlated to (P+1.2*S) content in the weld metal, which increases with increasing the dilution rate. Thus, it was found that the minimum critical strain decreases with increasing this content.

Furthermore, it was found that that the measure of the critical strain for the crack initiation during the test for high temperature ductility curve is accurate and the results corroborate with those of previous works.

IX-2531-15

Microstructure and mechanical properties in dissimilar friction stir butt weld between austenitic stainless steel and ferritic heat-resistant steel

Yutaka S. Sato, HiroyukiKokawa, Hiromichi T. Fujii, YasuhideYano, YoshihiroSekio

The study deals with the mechanical and microstructural characterization of a dissimilar friction stir butt welded joint between 6mm-thick base materials: austenitic stainless steel 316L and a tempered 11%Cr ferritic-martensitic F/M steel. Tests were conducted under a composite tool made of 60 vol% cBN- 40 vol% (W-25 wt.% Re: tungsten rhenium alloy) with two rotational speeds, namely 100 and 150 rpm. The tool travel speed and plunge depth were constant: 1 mm/s and 4.2 mm respectively.

The work concluded the following:

- formation of refined and defect-free weld.
- both sides of base materials are firmly joined each other, but without metallurgical reactions through a sharp zigzagging interface in the stir zone.
- the microstructure of the stir zone in both sides of the joint, consisting of ferrite-martensite in 11%Cr F/M steel and equiaxed single-phase in SS316, is much more refined than that of the corresponding base materials. However, the grain size of this stir zone increases with increasing the tool rotational speed.
- the hardness of the F/M steel increases sharply from 330 to 560 HV in its stir zone side near and at the joint interface. The rotational speed has no remarkable effect on this trend.
- the stir friction zone of the austenitic steel 316 exhibits a hardness increase from 185 to 240-285 HV due to the microstructure refinement.
- tensile tests showed that in all tested welds, the failure repeatedly occurs in the austenitic stainless steel zone. This confirms that the weld joint has higher strength properties than SS316.
- FSW is a reliable process to make sound joints between such dissimilar joints of stainless steel materials.

IX-2532-15

Hot Cracking Susceptibility of nickel base alloys 152 evaluated with PVR test

G.Tirand

The objective of the study is to characterize the hot cracking susceptibility, including solidification cracking and ductility-dip cracking DDC, of ten weld metal deposits of nickel-based 152 coated electrodes (SFA-5.11 ENiCrFe-7) that exhibit some compositional differences, namely in terms of C, S&P, Mn and Fe contents. Tests were conducted in the as-solidified condition for all batches.

Based on the results of this research, the following was concluded:

- The different deposited alloys exhibit roughly the same solidification temperature range with similar as-solidified microstructures, which contain small amounts of primary carbides and Laves phases.
- The variation in residual contents of sulphur and phosphorous do not really influence, as unexpected, neither the tendency to DDC nor the solidification cracking.
- Higher Fe and Mn contents improve the resistance of alloys to DDC. Besides, it has been found that the interdendritic space is enriched with manganese and niobium but depleted of iron. However, the weld deposits offering the best DDC resistance have a higher iron content in the interdendritic space, namely more than 9%, as compared to the welds with the poor DDC resistance.

VII. Sub-Commission IX-C Creep and heat resistant welds

Chair: Prof Peter Mayr (Germany)

IX-2534-15 (IX-C-1048-15)

Influence of Electron Beam Welding Parameters on Microstructure and Mechanical Properties of Boron-added Modified 9Cr-1Mo Steel Weld

C.R.Das, A.K.Bhaduri, S.Raju, R.Balakrishnan, S.Mahadevan, S.K.Albert, P.Mastanaiah

The study focuses on the effect of welding speed of EBW without filler metal on the microstructure and mechanical properties of a normalized and tempered boron-added modified P91B steel. The study deals with three welded joints performed with different welding speeds that correspond to different heat input levels (720, 1125 and 1212 J/mm) before undergoing a PWHT at 760 °C/3h.

It has emphasized that only the microstructure of the weld metal performed with the highest heat input does not retain delta-ferrite after PWHT. This is due to the sufficient cooling time that leads to a complete delta ferrite-to-austenite transformation at high temperatures, namely in the range of 1235-860 °C, which corresponds to the stability of austenite. It should be noted that to date there is no empirical formula including the effect of the cooling rate for the assessment of the susceptibility of high Cr-steels to stabilize delta-ferrite at room-temperature.

From the results of the impact test, it was found that the upper-shelf energy of the base metal is remarkably higher than that of the different EB weld metals. The latter behave roughly the same on this upper-shelf while having a similar impact energy at room temperature. The influence of welding parameters on the upper-shelf of the weld energy weld is insignificant. However, the welds show lower ductile-to-brittle transition temperatures (DBTT) than the base metal. Furthermore, welding with a slow travel speed or a high energy prevents the delta-ferrite retention in the microstructure, which further decreases the DBTT.

IX-2535-15 (IX-C-1058-15)

Effects of retained δ-ferrite on corrosion properties for modified 9Cr-1Mo steel welds

Sung-Yong Ahn, Myungjin Lee, Kyung-Mox Cho, and Namhyun Kang

The study aims to investigate the effect of retained delta-ferrite on the pitting corrosion of modified 9Cr-1Mo weld metal subjected to a PWHT at 760 °C for different holding times, from 30 mn to 2 hours. The PWHT was applied on autogenous GTAW welds performed on 6 mm thick normalized and tempered plate. Prior to welding, the final microstructure of the plate consists of tempered martensite (TM) with no delta-ferrite.

It was found that the autogenous welding causes delta (δ)-ferrite to appear in the martensitic microstructure of the weld. This is due to the insufficient time for delta-ferrite to transform into austenite during the fast cooling. The PWHT resulted in a tempered martensite with the precipitation of $M_{23}C_6$ (M: Cr, Mo) carbides and MX carbonitrides (M: Nb, V; X: C, N). The $M_{23}C_6$ particles precipitate along the TM/TM and δ/TM interfaces. Also, the Cr-rich $M_{23}C_6$ carbides become coarser and densely segregated along the δ/TM interface than at TM/TM interface with increasing PWHT holding time. The coarsening of carbides at δ/TM interface is due to the fact that this zone is more rich in Cr and C diffusing from δ-ferrite and martensite sides respectively.

The δ-ferrite laths and δ-ferrite/tempered martensite interface were the predominant sites of pitting attack. Cr depleted zones around Cr-rich $M_{23}C_6$ act as privileged sites for pitting initiation. Potentiodynamic test elucidated the deteriorating effect of longer PWHT times on the pitting corrosion resistance of the weld metal.

IX-2548-15 (IX-C-1051-15)

Low Heat Input Gas Metal Arc Welding for Dissimilar Metal Weld Overlays Part I: The Heat Affected Zone

Julian Frei, Boian T. Alexandrov, Michael Rethmeier

This study addresses the phase transformations, microstructures, hardness and bead tempering in the HAZ of Alloy 625 WOL's (Weld Overlays: ERNiCrMo-3) deposited by cold metal transfer (CMT) on low alloy ferritic steels ASTM A335 grades 11 and 22.

The CMT produces a narrow HAZ due its low arc energy, which leads to a small penetration degrees and lower dilution rates.

The high heating and cooling rates and lower dwell times result in limited carbon diffusion and incomplete carbides dissolution in high temperatures HAZ. This gives raise to either an inhomogeneous ferritic-martensitic microstructure in ferrito-pearlitic steels such as Gr 11 welded in their as-rolled condition or, otherwise, to a homogenous martensitic microstructure in normalized and tempered steels like Gr 22.

The intercritical HAZ in both studied steels corresponds to a mixture of the unaffected base metal and the partially transformed structure at the high temperatures HAZ. The microstructure undergoes a partial transformation and a partial refining as the temperature increases from the unaffected metal towards the high temperatures HAZ.

Since only two discernable temperature-regions may be discerned when using this low heat input CMT welding process, it was thus suggested to redefine the conventional HAZ as composed of two areas:

1- high temperatures HAZ including coarse-grained (CG) and fine-grained (FG) HAZ;
2- Intercritical HAZ.

CMT promotes bead tempering of the HAZ sine it produces thin weld beads and narrow HAZ. Pass welds are tempered by the heat generated from the next pass in the same layer and the passes of the following layer. The effect of bead tempering can also be promoted by slightly increasing the heat input from one layer to the next.

VIII. Sub-Commission IX-NF: Non-ferrous metals

Chair: Dr Jorge Dos Santos (Germany)

IX-2539-15

Effect of the interface characteristics on the joint properties and diffusion mechanisms during ultrasonic metal welding of Al/Cu

Jean Pierre Bergmann , Anna Regensburg, René Schürer

The study investigated the case of a hybrid joint between a pure stranded aluminum Al99.5 wire connector (50 mm^2) to 3 mm thick Cu-ETP (Electrolytic Tough Pitch) terminal. Welding tests were carried out using unplated, Ni-plated (chemical, galvanic) and Sn-plated terminals in order to characterize the role of the interface layer during US welding.

It was found that joints involving galvanically Ni-plated terminals exhibit an improved peeling resistance than those with chemically Ni-plated terminals whereas the plane Al-Cu joints exhibit the weakest bond. The nickel layer reduces the heat dissipation from the joint during joining operation.

Joining Al to Sn-plated Cu absolutely requires low amplitudes and long welding times under high welding forces. However, the quality of this type of joints deteriorates by the occurrence of micro cracks within the interface or between strands. Besides, due to its low melting point, tin plating tends to be pushed into the cavities between single strands.

Ultrasound welding is a well suited process for dissimilar joining of such type of joints under adjusted parameters (welding force, amplitude, time). The joint integrity depends on several surface parameters, namely oxide layer, surface morphology, thermal conductivity and heat dissipation, etc.

IX-2540-15

Study of the effect of tool geometry on semisolid stir welding of a AZ91 magnesium alloy

Vahid A Hosseini, Hossein Aashuri, Amirhossein Kokabi

Semi-solid stir welding is carried out on AZ91 magnesium alloy using Mg-25Zn as an interlayer filler metal in the groove joint under different rotational speeds of the stirring tool (drill-tip, round shape). The base metal and the interlayer filler metal were heated to 530 °C, corresponding to the semi-solid state.

It was shown that the semi-solid stir welding produces sound welded joints without oxide traces in the interface base metal-weld joint. Regarding the shape of the stirring tool, it was found out that the latter influences the features of the solidified weld metal. In fact, the most particular interest of the round shape stirrer, when compared with the drill-tip shape, lies in the smaller porosity in the weld metal and the improvement of bending strength ratio of joint to base metal

IX-2542-15

Considerations of nominal structural stress and intermetallic compound in resistance spot welded steel/aluminum joints

Tobias Broda, Steffen Keitel, habil. Jean Pierre Bergmann

The study deals with RSW regarding an overlap dissimilar joint of 1.5 mm sheets of uncoated low carbon steel DC04 and Al-5754. Welding was made using two types of surface preparation:

- Ultrasonic welding preparation (USP): surfaces were scrubbed and activated by an oscillating friction using an ultrasonic welding machine. This condition of preparation leads the steel side to penetrate 0.1 mm into the aluminum sheet. Sheets were spot welded after the contact between them became firmly protected.
- Surfaces are only sanded (sand preparation: SP) before spot welding.

Both materials do not share the same melting pool due to the difference of their electrical and thermal properties.

It was found that the intermetallic compound layer (IMC) in the interface increases with increasing welding time in both preparation conditions. These IMC consists of $FeAl_3$ and Fe_2Al_5 in both conditions. However, the growth rate of these intermetallic precipitates corresponding to SP condition is lower than in USP condition. This last condition (USP) gave rise to a thicker IMC. Despite this, IMC thickness in the USP preparation does not affect the tensile shear of the joint, which reaches the minimum tensile strength of annealed Al 5754. This behavior is explained by the form of the joint where the steel is inserted into the aluminum sheet. Contrary to USP, the shear load in the SP condition is affected by welding time and thus by the IMC thickness.

IX-2541-15

FRICTION-SPOT WELDING OF ALMGSC ALLOY

Junjun Shen, Sara Lage, Uceu Suhuddin, Jorge F. dos Santos

This research studies the weldability and the resulting mechanical properties of the welded joint of the AlMgSc alloy Ko8542 using the friction stir spot welding process. The microstructure of this alloy is strengthened by the precipitation of coherent Al_3Sc particles.

It was found that the obtained weld joint is defect-free and its strength increases with increasing the sleeve plunge depth or decreasing the tool rotational speed. The average failure load of the joints is 8.4 kN, which represents more than twice that required by AWS specification for aluminum resistance spot welds.

The process leads to the softening of the material outside the stirred zone. Besides, a recrystallization took place in all zones except near the center of the weld.

Friction spot welding is a promising joining process for aluminum alloys and is considered as an alternative to the current riveting process.