JCSE The Journal of Corrosion Science and Engineering
ISSN 1466-8858 Volume 16, Preprint 49 submitted 8 July 2013

High temperature corrosion studies on GTA and PCGTA weldments of AISI 430 and AISI 304 exposed in molten salt environment

S.N. Sabareshkumar[1], T. Prashanth[1], S. Swarannagarajan[1], R. Sridhar[2], P. Prabaharan[1], K. Devendranath Ramkumar[1], N. Arivazhagan[1], K. Gokul Kumar[1]
[1] *School of Mechanical & Building Sciences, VIT University, Vellore -632014, India*
[2] *Saraswathy Velu College of Engineering, Sholinghur, Vellore, India*

deva@vit.ac.in

Abstract
In this present investigation, a comparative analysis is made to examine the microstructure and mechanical properties of Gas Tungsten Arc (GTA), Pulsed Current Gas Tungsten Arc (PCGTA) welded dissimilar ferritic stainless steel (AISI 430) and austenitic stainless steel (AISI 304) using E309L filler material. Tensile tests on the dissimilar weldments reveal that the fracture occurred at the parent side of AISI 430. Hardness measurements showed that PCGTA weldments show higher hardness values as compared to the GTA weldments. Cyclic hot corrosion studies were conducted on the various zones of the GTA and PCGTA weldments at 600 °C in the aggressive molten salt environment containing Na_2SO_4 -60 % V_2O_5. The hot corrosion products were investigated using the combined techniques of SEM/EDAX analysis.

Keywords:

AISI 304, AISI 430; Gas Tungsten Arc Welding; Pulsed Current Gas Tungsten Arc Welding

1.Introduction
Austenitic stainless steels are widely used in versatile engineering applications in power generation, oil & petroleum industries and refineries, chemical, offshore and pharmaceutical applications because of its high corrosion resistance and strength. AISI 304 is the basic grade of stainless steel which has quite enhanced properties and most commonly available. Austenitic stainless steels are very corrosion resistant in a wide range of corrosive media and they can be used in a wide range of temperatures, from cryogenic conditions up to about 1150°C. Ferritic stainless steel can also be effectively used in sea

water as it is highly resistant to corrosion. Recently, ferritic stainless steels have been developed to substitute austenitic stainless steels in some applications, as automotive exhaust components, specially the upstream part of the exhaust line (manifold, down-pipe, converter shell), where temperatures can reach 1100°C [1]. It is always more challenging to join dissimilar metals as compared to similar metals due to the large differences in physical, metallurgical and mechanical properties. The dissimilar combination of AISI 304 and AISI 430 is widely used in $TiCl_4$ reduction retorts. Ferritic-to-austenitic dissimilar metal welds are used in a variety of industries including power generation, petrochemical, pulp, and paper.The major problem identified in welding ferritic stainless steel is the formation of coarse grains in the weld zone and heat affected zone of fusion welds. This will affect seriously in low toughness and ductility [2, 3]. It was reported [4-5] that welding of ferritic to austenitic stainless steels is considered to be a major problem due to difference in coefficient of thermal expansion, which may lead to crack formation at the interface, formation of hard zone close to the weld interface, relatively soft regions adjacent to the hard zone; large hardness difference between the hard and soft zones would also persist in this type of joints. Research work has been carried out on the dissimilar welding of ferritic - austenitic stainless steel using Electron Beam Welding (EBW), Friction Welding (FW) and GTAW processes by Reddy et al. [4], CO_2 laser beam welding by Anawa et al. [7]. This paper reports the weldability, microstructure and the mechanical properties of GTA and PCGTA welded dissimilar AISI 430and AISI 304. The primary molten salt environment found in the power plant includes Na_2SO_4 - 60% V_2O_5. Prakash et al., [8], reported that out of 89 failures occurring in one year, 50 failures were found to be due to hot corrosion and erosion by ash. The correlation between the microstructure, mechanical and hot corrosion behaviour of these weldments employing E309L forms the goal of the study and therefore assumes special focus on these weldments since such detailed studies are not hitherto reported.

2. Experimental

The candidate and filler materials employed in this study are AISI 430 and AISI 304, E309L respectively and their chemical composition is given in Table 1. The welded dissimilar AISI 430 and AISI 304 has the dimensions 100 mm x 50 mm x 6mm employed in this study. A special welding jig (rigid fixture) is designed and fabricated to hold the samples in alignment and to avoid bending during welding. Standard butt joint configuration is selected for the current study. GTA and PCGTA weld parameters employed for welding these dissimilar metal combinations for all passes are mentioned in Table 2.

JCSE The Journal of Corrosion Science and Engineering
ISSN 1466-8858 Volume 16, Preprint 49 submitted 8 July 2013

Table 1 Chemical Composition of base metals and filler material

Base Metal / Filler Material	Composition, % Wt									
	C	Cr	Ni	Mo	Mn	Si	S	P	Ti	Fe
AISI 430	0.08	12.0	Nil	Nil	1.0	1.0	0.045	0.045	0.6	Bal
AISI 304	0.08	18.5	8.5	Nil	2.0	1.0	0.03	0.045	Nil	Bal
E309L	0.035	Bal	12.6	Nil	1.58	0.53	0.021	0.024	Nil	61.76

Standard metallographic procedures are carried out to examine the various regions of the weldments by electrolytic etching (10% Oxalic Acid; 6V DC supply; Current density of 1 Amp/Cm^2) using Carl Zeiss optical microscope. The microhardness evaluation is carried out across the width of the dissimilar welded samples covering all the regions of the weldment using Vicker's Micro-hardness tester. A standard load of 500gf is applied for a dwell period of 10 s and the measurements are carried out at regular intervals of 0.25mm. Further the weldments are characterized for the strength by conducting tensile studies. Tensile test trails are carried out on the typically dimensioned samples as per ASTM E-8 standards using Electronic Tensometer.

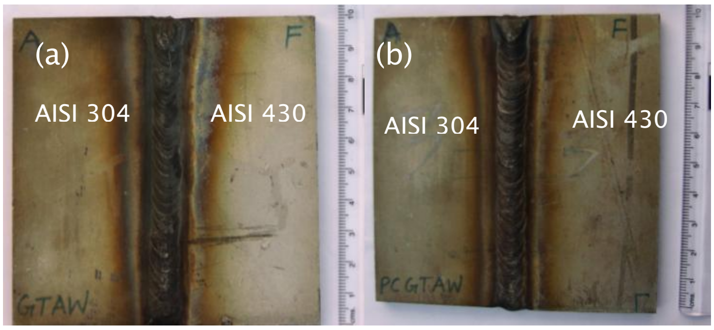

Fig. 1 Dissimilar welments of AISI 304 and AISI 430 using (a) GTAW (b) PC-GTAW process

Studies were performed on the different regions of welded samples each measuring 5 mm x 5 mm x 6 mm and also on the composite region [Parent metal + HAZ + Weld] measuring 30 mm x 10 mm x 6mm to estimate the corrosion behaviour for 50 cycles (each cycle consists of 1 hour heating followed by 20 minutes of cooling in room temperature) at 600°C. The specimens were mirror polished down to 1 µm before the corrosion run. A coating of uniform thickness with 3.0 to 5.0 mg/cm^2 of Na_2SO_4 - 60% V_2O_5 was applied and the samples were pre-heated to 200°C. The weight gain or loss of the spalled scale was included at the time of measurement to determine the rate of corrosion. The corroded samples of various regions were characterized for SEM/EDX analysis.

JCSE The Journal of Corrosion Science and Engineering
ISSN 1466-8858 Volume 16, Preprint 49 submitted 8 July 2013

Table 2 Welding parameters

Welding Process	Current (Amps)	Voltage (V)	Filler wire dia. (mm)	Shielding Gas	Flow rate (lit/min)	Peak current (Amps)	Base Current (Amps)	Frequency (Hz)
GTAW	143	17	2.4	Argon	15	---	---	---
PCGTAW	---	17	2.4	Argon	15	143	43	30

3. Results

3.1 Macrostructure and Microstructure of the weldments

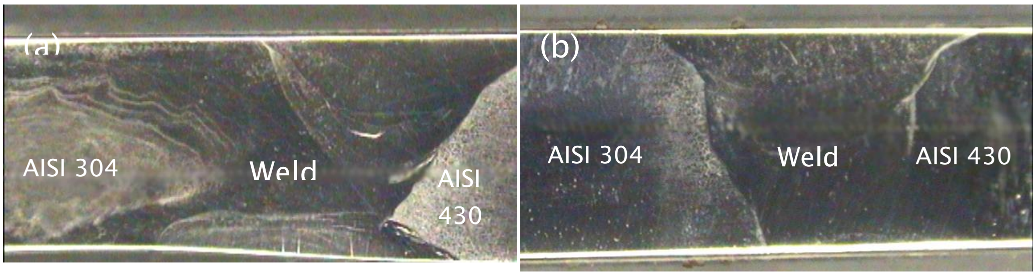

Fig. 2 Macro-photographs showing (a)GTA (b) PC-GTA weldments

Macrographs of the welded dissimilar AISI 304 and AISI 430 shown in (Fig. 1 and Fig.2) reveal that the welds obtained from both the processes show better fusion with the base materials. Microstructure examination (Fig.3) on these weldments shows that the HAZ exhibited a large, fully ferritic grain structure typical of fully ferritic materials with insufficient secondary phases. Long dendrites of δ - ferrite are usually observed in the weld region. In addition, the grain boundary martensite formation is also observed in the fusion zone of AISI 430 for both GTAW and PCGTA weldments.

3.2 Hardness measurement

Hardness measurements are carried out across the width of the weldments (Fig. 4). The maximum hardness is observed at the weld region for both the weldments. The average hardness value of the GTA weldments is 189.3 HV whereas for PCGTA weldments, it was found to be 203.8 HV. However the hardness value was found to be higher in the weld region of GTA as compared to the PCGTA weldments. Since both the welding processes utilize austenitic filler wire, the weld region is well matched with AISI 304 side. It is also observed that the HAZ of AISI 430 has maximum hardness as compared to the base metal in case of PCGTA weldments.

3.3 Tensile Test

Tensile test trails on the weldments obtained from both the processes reveal that the fracture occurred at the parent metal of AISI 430 side (Fig. 5(a) - 5(c)). The average tensile strength of the GTA weldments is found to be 486 Mpa and 493 Mpa for PCGTA weldments. Also the percentage elongation at break load is 23.06% and 26.8% for GTA and PCGTA weldments respectively. The fracture is noticed to have a typical cup and cone type of fracture.SEM fractographs shown in Fig. 5(d) and 5(e) revealed the formation of large number of dimples and micro-voids found spread across the fracture regions which coalesce to undergo the ductile mode of failure for both GTA and PCGTA weldments.

3.4 Hot Corrosion and SEM/EDAX analysis

Thermogravimetric data of the hot corroded GTA and PCGTA weldments at the end of the 50th cycle after exposing to the molten salt environment were represented in Fig. 6(a) and 6(b). Weight gain was observed at all the zones of the weldments in both the cases. The spalled scale is also included at the time of measuring the weight changes. In case of GTA weldments, the parent metal and HAZ of AISI 304 has acquired the maximum weight gain as compared to other zones. Weld region of GTA weldments had shown better resistance to corrosion. Whereas for PCGTA weldments, the HAZ of AISI 304 has acquired the maximum weight gain and shown least corrosion resistance as compared to the other zones of the weldments. Weld zone of the PCGTA weldments had also undergone an increase rate of corrosion. SEM/EDAX analysis was carried out on the hot corroded samples of GTA and PCGTA weldments as shown in Fig.7 . The weld zone of PCGTA weldments has undergone severe attack due to the molten salt environment. This may be due to the formation of the spinel FeV_2O_4 and $CrVO_4$ which contributed for the corrosion attack. It was reported that the effect of adding Cr to Ni was found to be beneficial in the Na_2SO_4 melt. However, on increasing the VO_3- concentration in the melt, this effect has diminished, becoming harmful in pure NaVO3 due to the formation of the non- protective $CrVO_4$ [Sidky and Hocking (1994)].

4. Discussions

Dissimilar joints of austenitic and ferritic stainless steels could be successfully welded by GTA as well as PCGTA welding processes using E309L filler wire. It is apparent from the macro-photographs that good fusion and also the absence of macro-scale deficiencies could be obtained. The microstructure inveterate the formation of vermicular - ferrite and the austenite formation in the weld region of GTA sample (Fig. 1). Adjacent to weld region, grains were coarser and in addition the formation of grain boundary martensite on HAZ was clearly observed on the AISI 430 side. The formation of martensite on the AISI 304 side might be influenced by the heat supplied during welding. Whereas on the PCGTA weldments, uniform short dendrites were observed on the weld region. Absence of any micro-segregation effects, formation of secondary phases could be observed in both the GTA and PCGTA weldments.

It is also a well known fact that PCGTA welding normally yield the finer grains at the adjacent zones of the weld. It was clear from that hardness trend that the hardness of the HAZ side of AISI 304 and AISI 430 was found to be higher for GTA as compared to PCGTA weldments. The HAZ of AISI 430 was found to possess higher hardness which could be attributed due to the martensite formation on the HAZ side, which is also confirmed from the microstructure examination. In addition, the tensile results showed that the fracture occurred at the parent metal side of AISI 430 side. It could be confirmed that the weld strength of both GTA as well as PCGTA weldments are found to be higher than that of the parent metal. Due to the finer grains present in the PCGTA weldments, the tensile strength was found to be more as compared to GTA weldments which is also evident from the hardness trend.

Jayaganthan et al. (2008) conducted hot corrosion studies on Ni and Fe-based superalloys in an aggressive environment containing Na_2SO_4 – 60%V_2O_5 at 900 °C. They reported that $NaVO_3$ acts as a catalyst and also serves as an oxygen carrier to the base alloy through the open pores present on the surface, which will lead to the rapid corrosion. Also, the spinel oxide $NiAl_2O_4$ formed during the hot corrosion showed better corrosion resistance as compared to NiO. It is well understood from the SEM/EDAX analysis that the non-protective $CrVO_4$ and FeV_2O_4 scales are formed and contributed for the corrosion.

Conclusions

[1] Defect free welds of dissimilar AISI 430 and AISI 304 could be obtained by employing GTA as well as PCGTA welding processes

[2] Fracture occurred at the parent metal side of AISI 430 (ferritic stainless steel) for both GTA and PCGTA weldments

[3] The ultimate tensile strength of the PCGTA dissimilar welds are found to be higher as compared to GTA welds

[4] Presence of spinel oxides $CrVO_4$ and FeV_2O_4 contributed for corrosion attack in the molten salt environment

References

[1] Carlos Eduardo Reis de Carvalhoa, Geraldo Magela da Costaa, André Barros Cotab, Edson Hugo Rossic. High Temperature Oxidation Behavior of AISI 304 and AISI 430 Stainless Steels, Materials Research, Vol. 9, No. 4, 393-397, 2006

[2] F.B. Pickering. Physical metallurgy of stainless steel developments, Int. Met. Rev. 21 (1976) 227-268.

[3] S. Kou. Welding Metallurgy, Wiley, 1987, pp. 383-386.

[4] S. Allabhakshi, G. Madhusudhan Reddy, V.V. Ramarao, C. Phani Babu, C.S. Ramachandran. Studies on weld overlaying of austenitic stainless steel (AISI 304) with ferritic stainless steel (AISI 430), National Welding Conference, Chennai, India, January 2002, Indian Institute of Welding, Paper 8.

[5] Omar. Effects of welding parameters on hard zone formation at dissimilar metal welds, Weld. J. 77 (2) (1998) 86s-93s.

[6] Welding Hand Book, 7th ed., vol. 4, American Welding Society, 1984, pp. 93-128.

[7] E.M. Anawa, A.G. Olabi, Effect of laser beam welding on toughness of dissimilar welded components, Applied Mechanics and Materials, Vols. 5 -6 (2006); 375 - 380

[8] Effect of Pulse Parameters on Weld Quality in Pulsed Gas Metal Arc Welding: A Review Kamal Pal and Surjya K. Pal, JMEPEG (2011) 20:918-931

JCSE The Journal of Corrosion Science and Engineering
ISSN 1466-8858 Volume 16, Preprint 49 submitted 8 July 2013

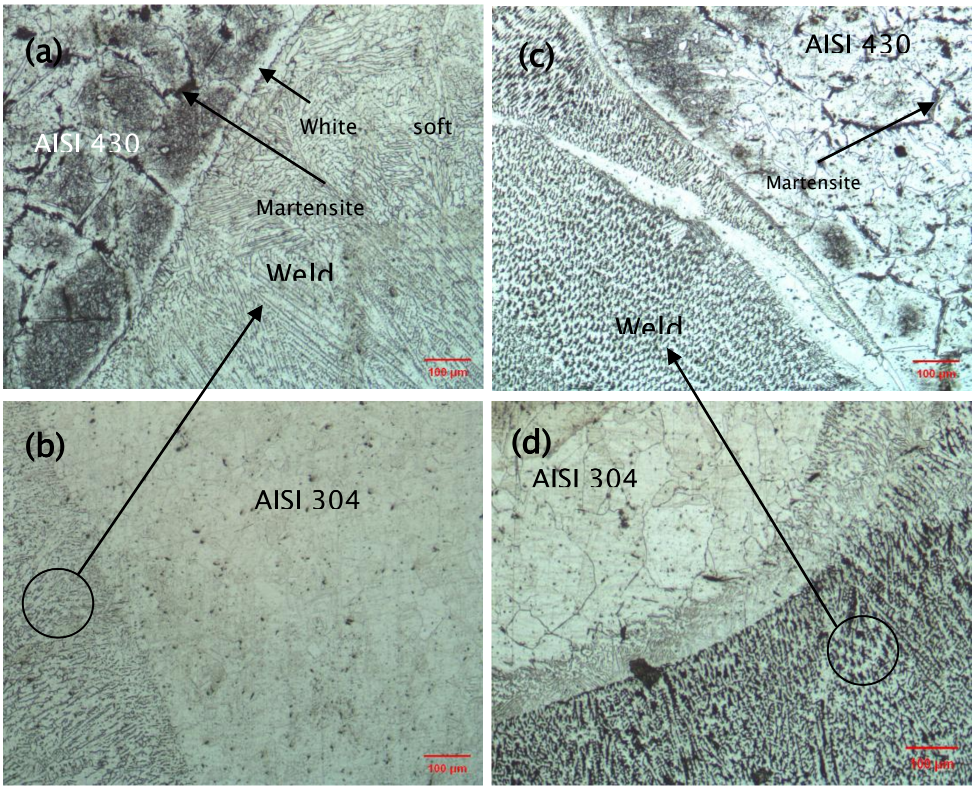

Fig. 3 Microstructures showing the various zones of welded AISI 304 and AISI 430 (a) & (b) GTA weldments (c) & (d) PC-GTA weldments

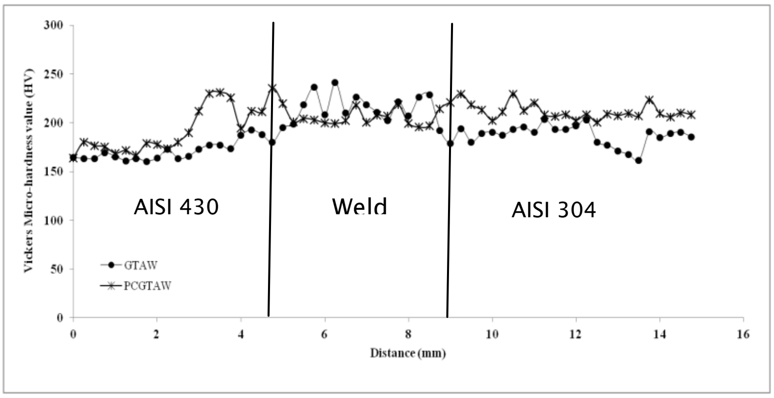

Fig.4 Hardness trend of the GTA and PCGTA welded dissimilar AISI 304 and AISI 430

JCSE The Journal of Corrosion Science and Engineering
ISSN 1466-8858 Volume 16, Preprint 49 submitted 8 July 2013

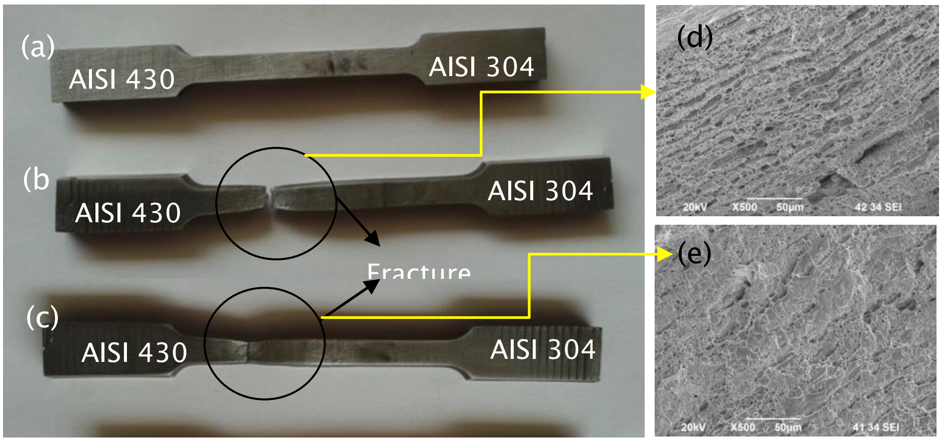

Fig. 5 Tensile studies on the dissimilar weldments (a) ASTM E8 Sample (b) Fractured samples of GTA weldments (c) Fractured samples of PCGTA weldments; SEM fractographs of (d) GTA weld sample (e) PCGTA weld sample

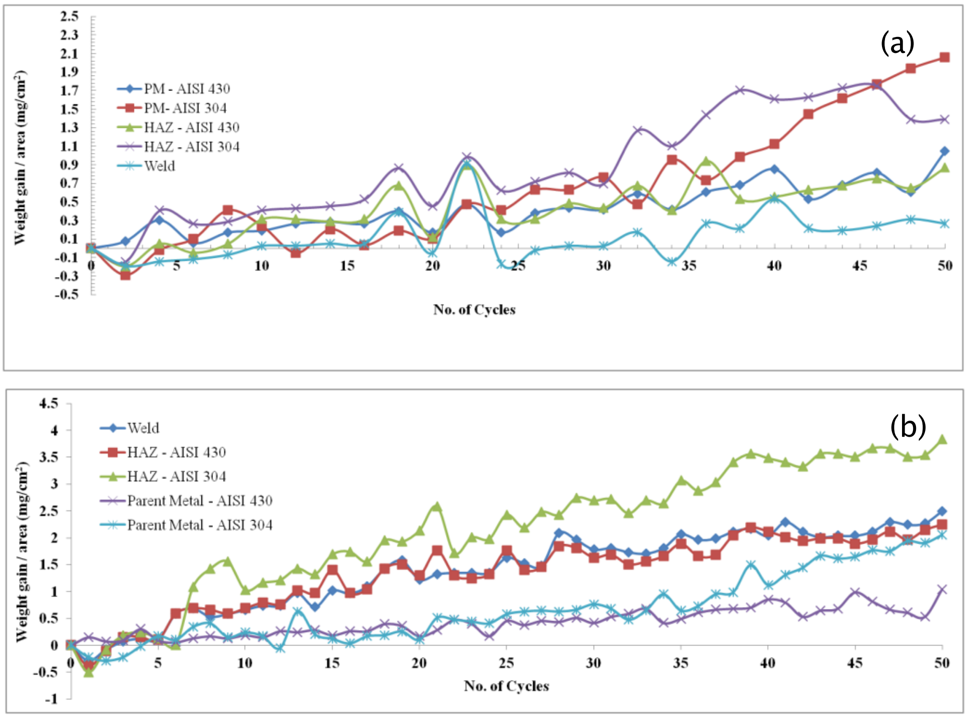

Fig. 6 Thermogravimetric analysis of (a) GTA weldments (b) PCGTA weldments exposed in the molten salt environment containing Na_2SO_4 – 60% V_2O_5

JCSE The Journal of Corrosion Science and Engineering
ISSN 1466-8858 Volume 16, Preprint 49 submitted 8 July 2013

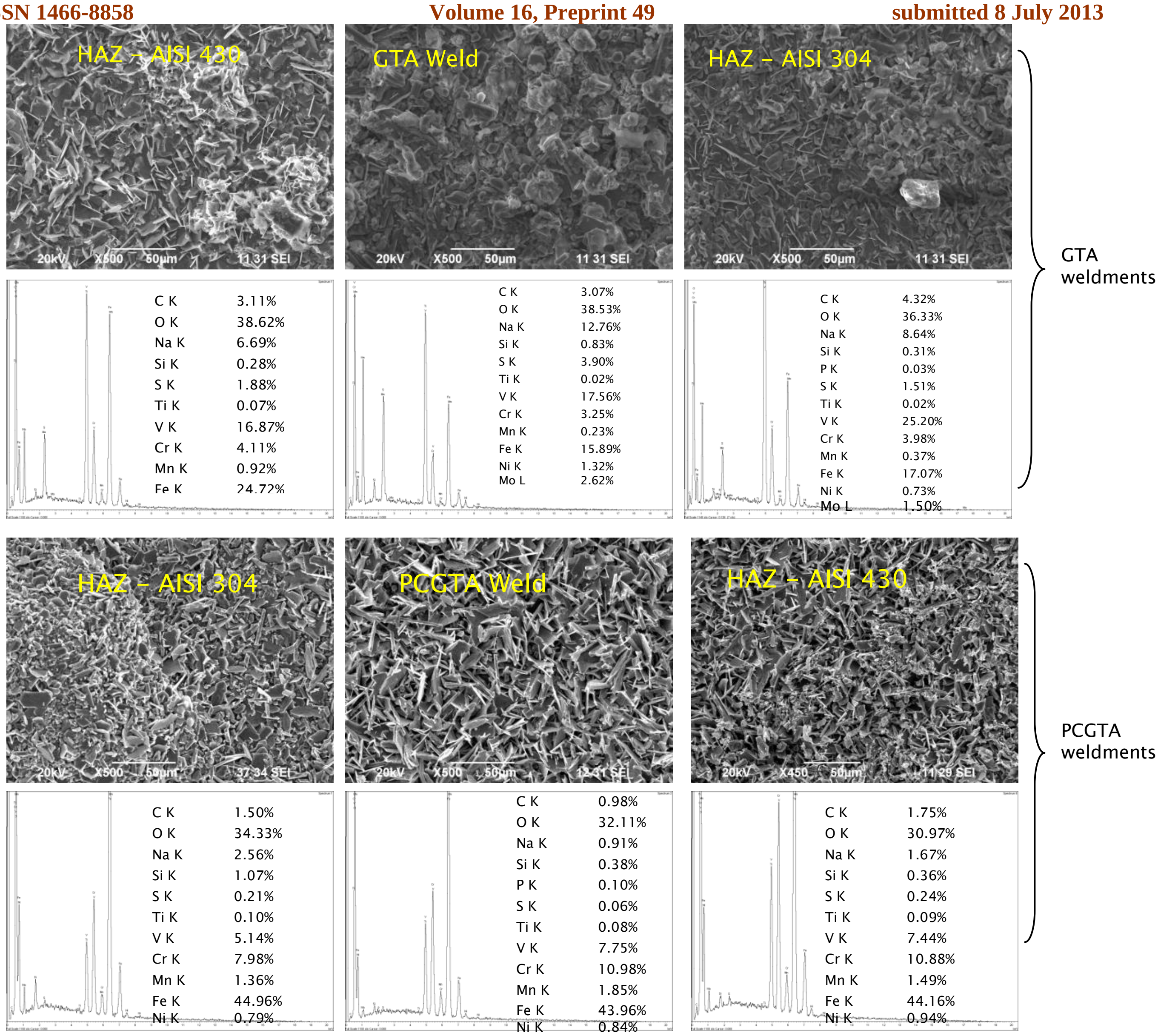

Fig.7 SEM/EDAX analysis of the hot corroded samples of GTA weldments and PCGTA weldments exposed in the molten salt environment containing Na_2SO_4 – 60% V_2O_5