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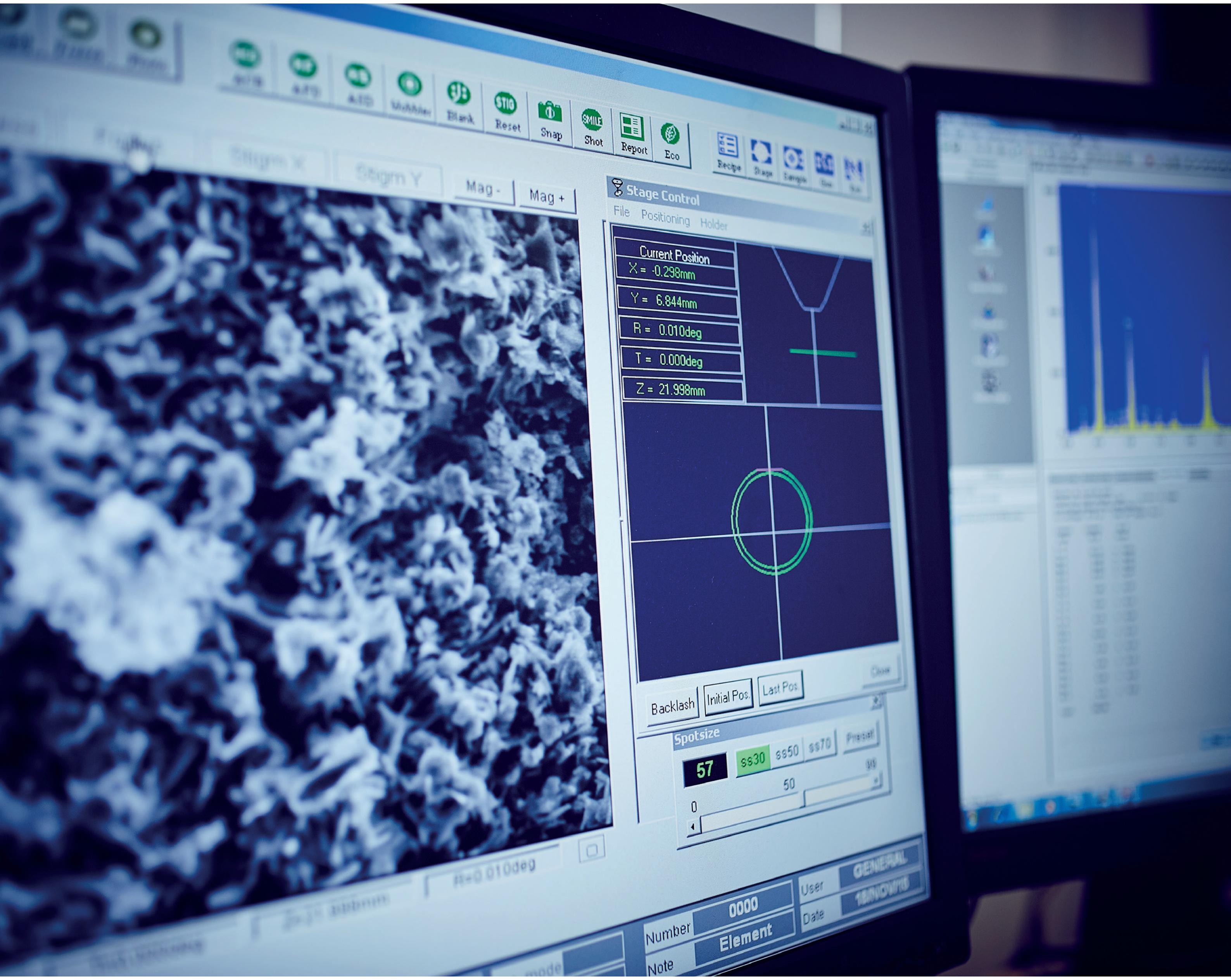


CASE STUDY

COPPER INDUCED CRACKING OF A TYPE 316L STAINLESS STEEL CIRCUMFERENTIAL BUTT WELD

CASE STUDY:

Copper Induced Cracking of a type 316L Stainless Steel Circumferential butt weld

SUMMARY:

In this case study, a newly constructed stainless steel pipingweld joint was found to be cracked. Non-destructive testing revealed the presence of extensive cracking in the weld metal, fusion boundary and heat affected zone (HAZ) regions. Metallurgical examination revealed cracking morphology in the weld to be interdendritic and in the HAZ to be intergranular. Copper rich regions were also observed within and adjacent to the cracking locations. SEM and EDS analysis of the cracked surface confirms the intergranular nature of cracking and extensive deposits of copper. The possibility of incorrect welding consumable (ERNiCu-7) was eliminated,as the weld metal chemistry matched with the requirements of ER316L. From this case study, it was concluded that contamination of copper particles on a workpiece surface melted and propagated into the fusion boundaries during the weldingprocess, weakening the austenite grain boundaries. Liquid metal (copper) reduced the bond strength within the grain boundaries and resulted in the formation of intergranular / interdendritic cracking. Sources of copper could not be positively identified from the information supplied by the client, however,may include the use of copperor copper alloy based welding fixtures, the use of a copper shoe on the pipe bore, bearing material on pipe rests or weld preparation apparatus.

BACKGROUND:

The information received from the customer showed that thestainless-steel pipe girth weld was cracked at various locations around the circumference. After the completion of welding, onsite dye penetrant examination revealed crack like indications at the outer diameter. Further radiographic examination, performed by client, confirmed the presence of cracking in the weld and HAZ. Stainless steel pipe of ASTM A312 Grade TP316L was welded using 316L filler wire. Welding process used was GTAW. Due to pipe weld joint cracking, customer was concerned, as the installation of the piping system was completed, and called into question if all the field weld joints were having same issues of cracking.

ANALYSIS:

VISUAL EXAMINATION:

Pipe section received in the lab was sectioned into two halves and a dye penetrant test was conducted at the outer diameter (OD) and inner diameter (ID) to locate the defective areas. After penetrant test, multiple linear indications were observed at both weld toes and in heat affected zone (HAZ). More than half section of the pipe was found to be defective. Closer views of the inner diameter side defect locations revealed cracking in the weld and the HAZ.

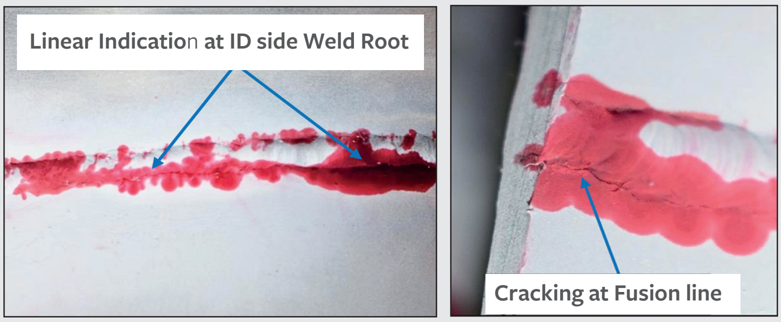


Figure 1(a): Penetrant test at ID side revealed half section of the pipe to be cracked. Cracking was observed in the weld and HAZ / fusion line.

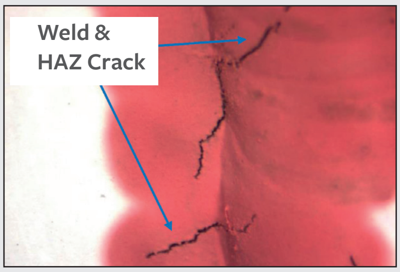


Figure 1(b): Low magnification stereomicroscope images revealed cracking in the weld and HAZ

MACRO EXAMINATION:

To observe the cross section of the cracked locations, a sample was removed from the cracked area, transverse to the weld, for metallurgical assessment. The macro analysis revealed cracking at the weld toe which was found to subsequently propagatethrough the weld. A further crack, in the heat affected zone was also observed found propagating through the HAZ towards the pipe outer diameter side. Low magnification stereomicroscope analysis revealed HAZ cracks to be transverse to the weld. Fusion line cracks were found to be oriented parallel to the weld.

Figure 2: Macrographs of the cross-sectional sample revealed cracks in weld and HAZ

MICROSTRUCTURAL ANALYSIS:

Microstructure of the weld was found to be fully austenitic, confirming an austenitic mode of solidification. Delta Ferrite was found to be mostly absent in the cracked weld regions. The solidification structure of the welds was found to be of mixed mode which was cellular dendritic and columnar. The cracks observed in the weld were predominantly located along the solidification grain boundaries separating a group of dendrites of one orientation from the other. Intergranular cracking was observed in the heat affected zone. No signs of sensitization of the austenite grain boundarieswas observed in the section taken. In the weld and heat affected zone, copper colour regions were observed both within the crack and along the dendrite boundaries indicating possible copper contamination of the weld.

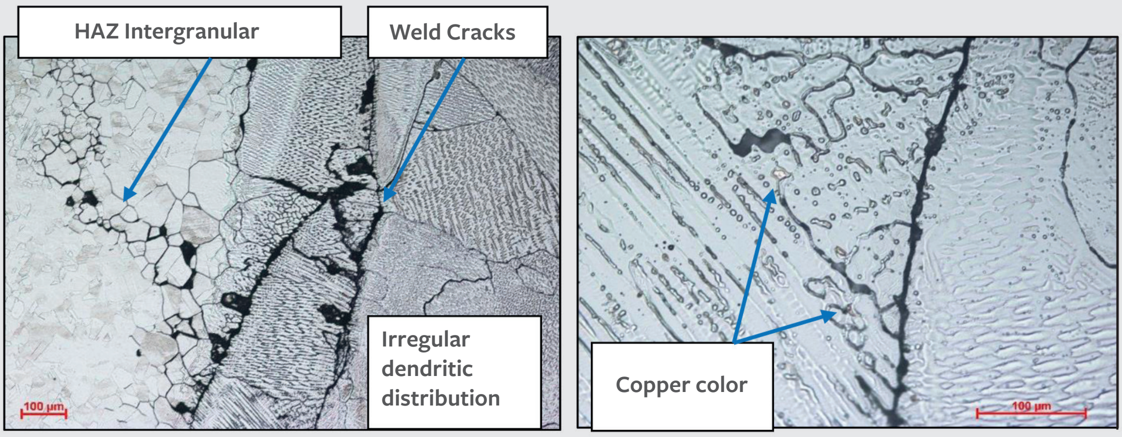


Figure 3: Photomicrographs shows cracking in the weld, HAZ and base metal.
Copper colour regions were observed along the dendrite boundaries

CHEMICAL ANALYSIS:

Chemical analysis of the weld root was carried out to determine chemical composition of the weld. Weld metal chemistry was found to be in conformance with the requirements of SFA 5.9 ER316L

SCANNING ELECTRON MICROSCOPY (SEM):

Part of the cracked weld was mechanically opened to analyse the cracked surface at high magnification using Scanning electron microscope (SEM). The exposed surface revealed cracking in the weld deposit to generally follow an interdendritic separation pattern and the heat affected zone cracking shows a ‘rock candy’ type of structurewhich is a typical feature of intergranular cracking. SEM confirms intergranular cracking of weld and HAZ which was also observed during microstructural examination.

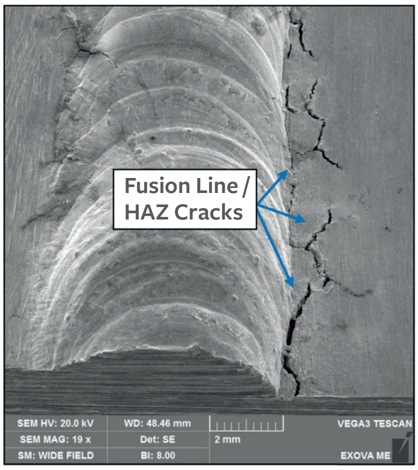


Figure 4: SEM analysis of weld root revealed cracking in the weld and the HAZ

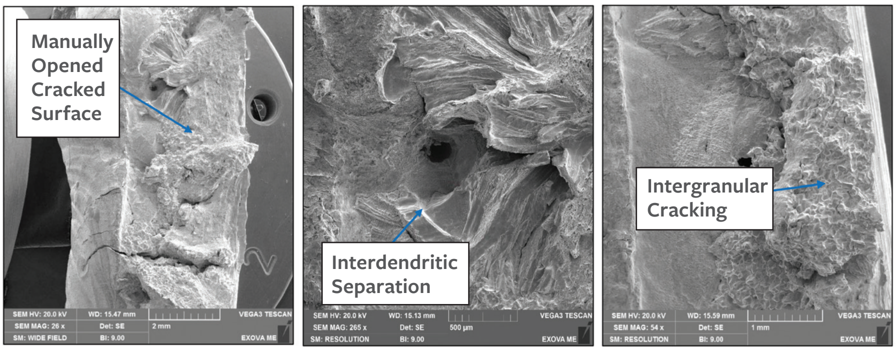
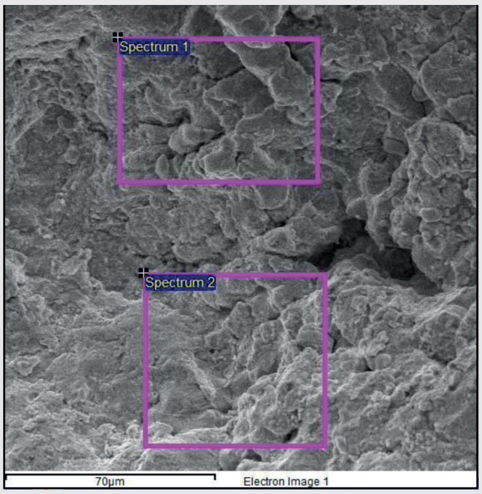


Figure 5: SEM analysis of mechanically opened cracked surface revealed interdendritic separation in the weld and intergranular cracking in the HAZ

ENERGY-DISPERSIVE X-RAY SPECTROSCOPY (EDS) ANALYSIS:

EDS analysis of the cracked surface revealed the presence of iron (Fe), chromium (Cr) and oxygen (O), indicating stainless steel oxidation products. Other stainless steel alloying elements, nickel (Ni) and silicon (Si), are also present. EDS spectra further revealed the presence of significant amounts of copper on the cracked surface which confirmed the contamination present within the weld during solidification.



Elements	Spectrum 1	Spectrum 2
C	5.87	7.75
O	16.56	17.3
Si	0.35	0.38
S	0.32	
Cr	15.3	13.7
Mn	4.53	3.67
Fe	32.74	32.71
Ni	9.8	10.04
Cu	13.63	12.96
Mo	0.9	1.48

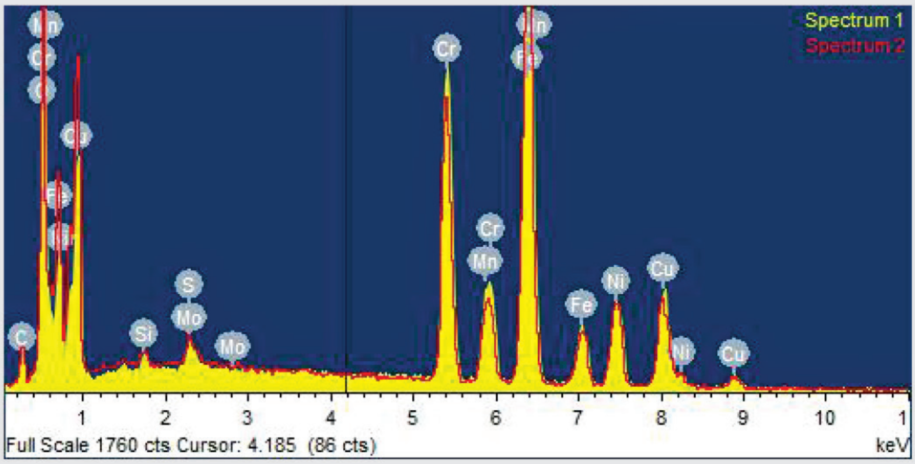


Figure 5: EDS spectra revealed the presence of high amount of copper on the cracked surface

CONCLUSION:

Metallurgical examination revealed cracking along the solidification grain boundaries in the weld & intergranular cracking in heat affected zone. Presence of copper colour regions within the cracks and along the dendrite boundaries, together with SEM / EDS analysis, confirms the cracking morphology to be interdendritic and intergranular of a 'brittle' type. EDS revealed unusually high amount of copper on the cracked surface. Chemical analysis results ruled out the possibility of the use of wrong filler wire (ErNiCu-7). Based on all observations, it can be shown that the weld and HAZ cracked due to a copper induced hot cracking phenomenon also known as copper contamination cracking (CCC). Liquid metal embrittlement has been determined to be the mechanism responsible for CCC. The cracking occurs when molten copper diffuses into, penetrates, and weakens austenite grain boundaries during solidification. The compromised boundaries subsequently fracture, either because of residual or applied stresses during cooling, forming a crack with little or no sign of any residual grain deformation. The source of copper contamination in this failure was,most likely, the use of copper or copper alloy-based welding accessories whichleft tracesof copper on the work piece surface.

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