

Failure Analysis of Butt Weld of Bimetal Composite Pipes

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Abstract The study aims to summarize the main failure morphology of butt weld of bimetal composite pipes which are used in a gathering pipeline of one condensate gas field with high temperature and high pressure, and then analyze the failed pipes with the methods such as SEM, energy spectroscopy, and metallographic examination. The experiments show that there is no Mo which is the key element of metal material to resist the pitting corrosion and stress corrosion in the organization of the welds. Through the microscopic morphology analysis it shows that the process of the gradual shedding of corrosion product film gives rise to the failure of pipelines. The gradual shedding of corrosion product will expose the new matrix to the corrosive environment which will accelerate further erosion. The cycle of the erosion continues and eventually leads to pipelines' leakage. The weld residual stress plays an essential role in the weld failure, besides, the existence of the residual stress will accelerate the collapse of the passivation film. The factors which lead to the weld failure are the special structure, organization of the weld, corrosive media, and the residual

stress of the weld. In view of the failure situation, we put forward the corresponding suggestions as follows.

Keywords Corrosion · Bimetal composite pipe · Weld · Failure analysis · Experiment

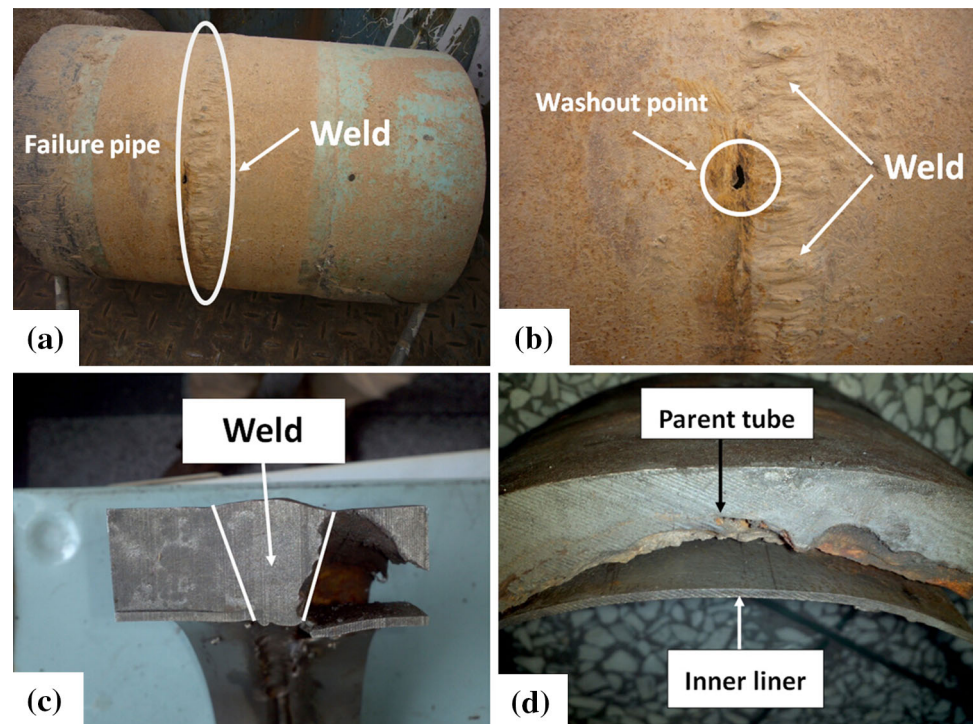
Introduction

The bimetal composite pipes combine the strength of carbon steel and the corrosion resistant of stainless or alloy steel in performance [1, 2]. The pipes are widely used in the transport of oil, gas, and refinery products [3]. Although the failure of gathering pipeline is largely reduced by using bimetal composite pipes, there are also individual failure cases. According to the analysis of the statistics of the perforation accidents of bimetal composite pipes in one of the condensate gas fields of China, we found that there are 50% of perforations which appeared in the butt weld of the bimetal composite pipes. The production manifold of this gas field has adopted composite pipes ($\Phi 273 \text{ mm} \times 26 \text{ mm}$ 20 G of parent tube + 2 mm 316 L of inner liner). The welding method between composite pipes adopts shielded metal arc welding (SMAW). In September 2010, the production manifold of 1# value group leading to the treatment station in this gas field generated a washout from inside to outside, the washout distances 1# value group 1900 m. The gas of the value group receives from 8 gas wells, and the daily intake amount to 300,000–450,000 cubic meters. The temperature of wellhead is above 60 °C. The gas from these wells contains CO_2 and Cl^- , and the content of Cl^- reaches to 1.38 g/L. This composite pipe was only used for 3 years, and not reached the requirement of its design service life greatly, belongs to early failure.

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Fig. 1 Failure pipe morphology

Macro Morphology

Macro Morphology Analysis

The pictures of failure production manifold as shown in Fig. 1.

Figure 1a, b shows the overall morphology of pipe washout point: there is an about 6 mm long and 2 mm wide washout point on the outer surface of this pipe. Cut along the washout point and the morphology of this pipe internal as shown in Fig. 1c, d. The weld of inner liner has no obvious signs of corrosion, but the corrosion of parent tube is severe. There are a lot of relative loose corrosion products in corrosion pits as shown in Fig. 1c. The inner liner around the washout point has no obvious corrosion signs, but the corrosion of parent tube corrosion is very serious. There are helicoids corrosion deep holes on the inner wall of parent tube. The inner wall of parent tube has been eroded away most as shown in Fig. 1.

The welding method of connecting composite pipes adopts uphill welding [4]. Therefore, we can judge the working range of the pipeline by observing the weld trend. In observational analyses, washout points are all in arc starting points of butt weld, which are located at the bottom of the pipe.

Sampling and Samples

In order to microanalyses the failure pipe morphology, we have cut the failure pipe with the method of wire-cutting. The weld without failure was cut into six parts by wire-cutting

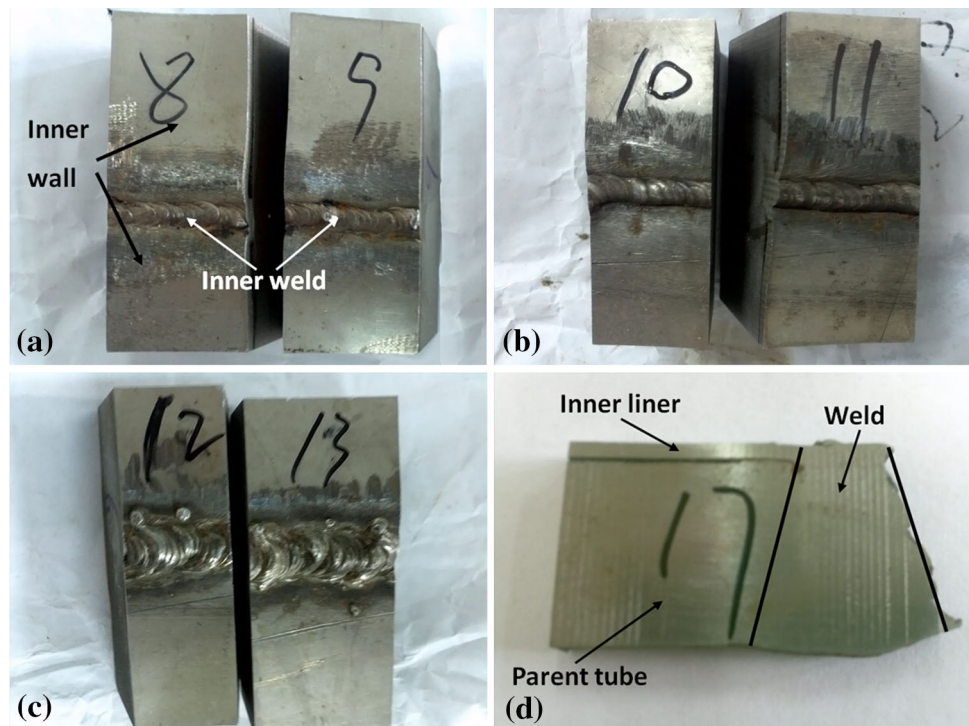
and was numbered 8–13. In order to observe the micro failure morphology near the corrosion pits, we have sampled on corrosion pits of washout, numbered 17 as shown in Fig. 2.

SEM Analysis

Morphology analysis of samples by SEM as shown in Fig. 3.

Figure 3 shows SEM results of weld inner surface. There are corrosion holes and microcracks on the inner surface of weld as shown in Fig. 3a. The cracks connect to corrosion holes and expand along corrosion holes. The corrosion hole was generated by pitting corrosion. The corrosion hole always promotes the generation of cracks. The existence of corrosion hole will cause stress concentration. The stress concentration would accelerate plastic deformation of corrosion holes surface and the break of passivation film. The matrix of weld is exposed to corrosion because of passivation film being broken, and lead to generate stress corrosion cracks. These cracks continue to expand forward, eventually leading to weld cracking. The media of pipeline transport into the gap of fusion line and form a large cathode-small anode corrosion cell. The corrosion cell accelerates the metal dissolution [5]. Cl^- in the medium and metal ions combined and formed chloride. The chloride is turned to hydrochloride by hydrolysis. The $\text{Ca}(\text{HCO}_3)_2$ in medium converted into CaCO_3 . Dissolved metals, hydrochloride, and CaCO_3 deposited outside the gap of fusion line as shown in Fig. 3b. There are transverse cracks on the weld bead as shown in Fig. 3c, and some parts of the oxide film have been shedding on the inner

Fig. 2 Samples



surface of weld. Transverse cracks are produced during the process of weld solidification and belong to solidification cracks. These cracks produced shrinkage, deformation, and tensile stress during the weld crystallization process. There are fusion line cracks in Fig. 3d, and these cracks belong to hot cracks. There are eutectic films in the base material. The melting point of eutectic film is lower than matrix, so the film would be melted during welding. The film will be cracked by contraction stress when the weld is cooling.

There are cracks near corrosion pits areas and extended to the inside weld as shown in Fig. 4a. As shown in Fig. 4b, there are plenty of small ball-like oxides in the morphology of corrosion pits. Figure 4c shows the corrosion product films that fell off. Cl^- has a strong penetrating power because of its small radius, so the Cl^- is able to penetrate the tiny cracks on corrosion product films [6]. Cl^- and metal ions of product films would produce chlorides. The chloride hydrolysis will cause decreased density of product films, and lead to falling off of the parts of films. Cl^- promotes the dissolution of newly exposed metal matrix, leading to the generation of corrosion [7]. Cl^- is the necessary condition of pitting corrosion, stress corrosion, and forming corrosion cell and occluded cell in crevice corrosion [8].

EDX

The function of EDX is qualitative and half-quantitative analysis of samples by understanding the samples' chemical composition.

Figure 5 and Table 1 show the weld and base metal EDX results of No. 11 sample. The results show that weld does not contain the Mo element, so the weld is Cr–Ni austenite stainless steel. The inner liner is Cr–Ni–Mo austenite stainless steel. The primary function of Mo element is to improve the strength of surface passivation film and enhance the corrosion preventive of stainless steel. Mo is the main element to improve the resistance to stress corrosion cracking of stainless steel in chloride solution [7].

There are product films in corrosion pits in the A area and shedding part of product films in the B area as shown in Fig. 6a. From Table 2, Fe element content in the product film is less than weld inner, and the Fe content of product film fell off area is little different with weld. This shows that the A region is the area of corrosion product films and the B region is the position of product films which have fell off. The above analysis results show that the speculation of corrosion product films abscission is correct. The main components of the corrosion product films are Fe oxides and small amount of Cr and Ni oxides. The main reason for the reduction of the content of Fe is because of the other elements addition such as Cl and corrosion product films abscission.

Metallography Analysis

The No. 11 sample was analyzed by metallography analysis in order to understand the effects of welding process on material microstructure.

Fig. 3 SEM results of No. 8–13 weld inner surface

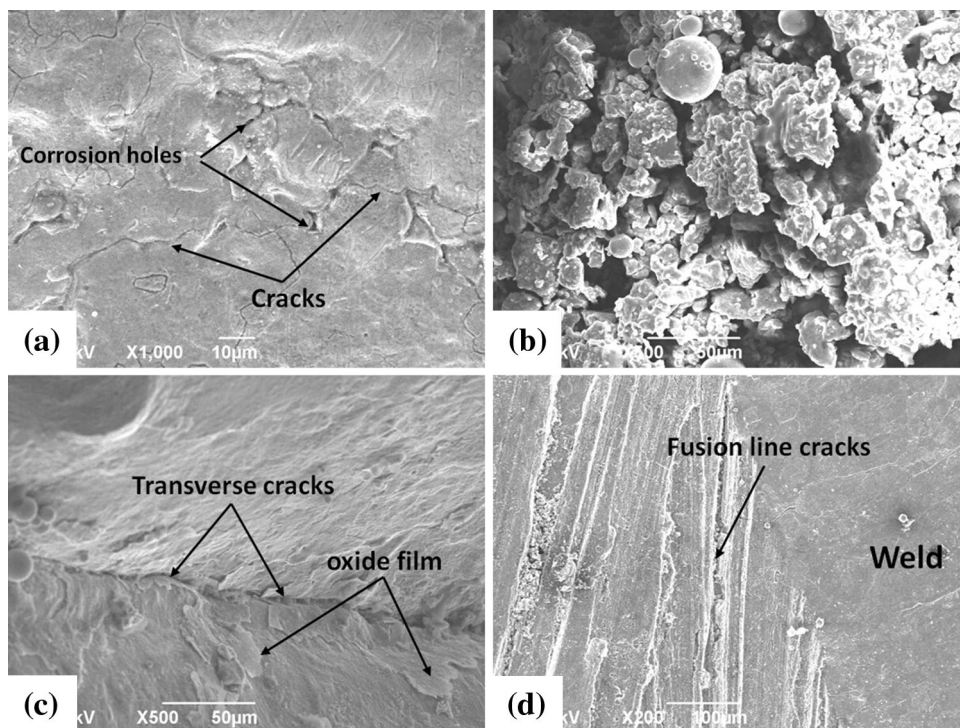
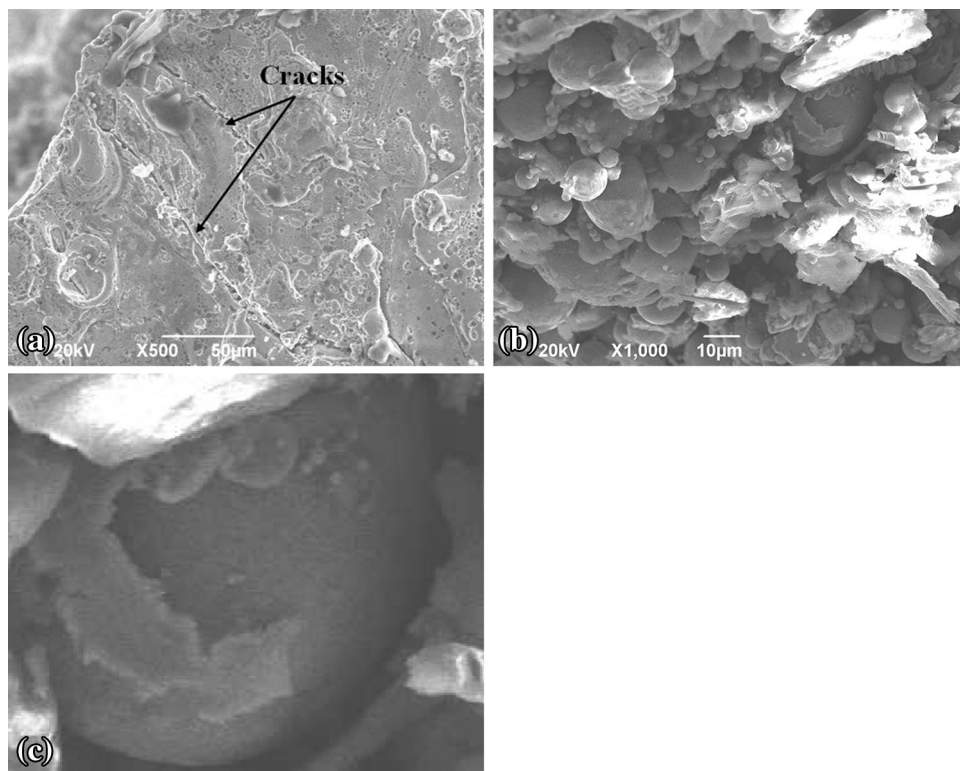


Fig. 4 The SEM morphology characteristics of corrosion pits in No. 17 sample



The microstructure of parent tube is rather dense ferrite and a small amount of pearlite as shown in Fig. 7a. The microstructure of liner tube is nubbly austenite [9] as

shown in Fig. 7b. The microstructure of innermost weld is austenitic with a small amount of ferrite and the ferrite vermicular distribution in austenite. Ferrite is helpful to

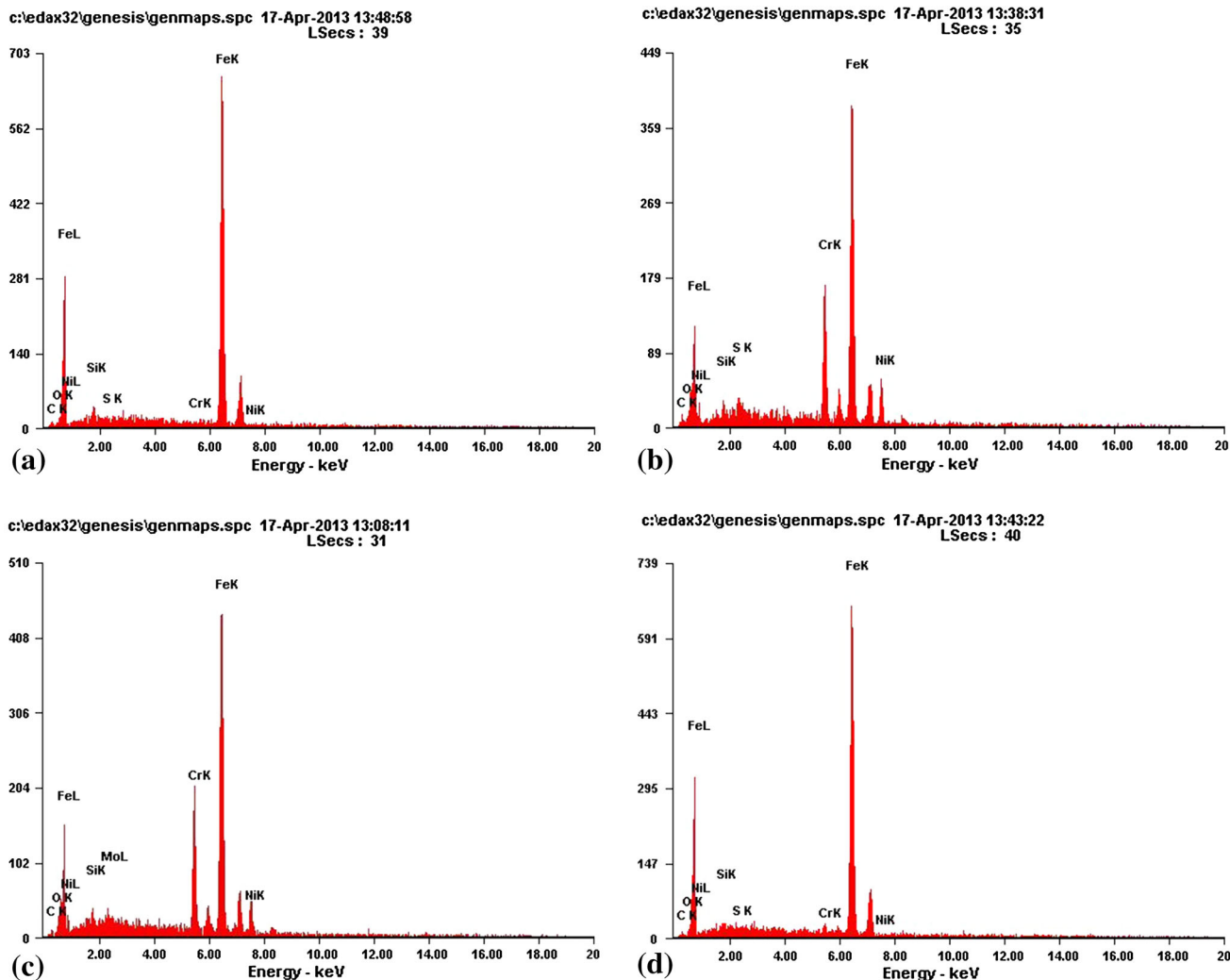


Fig. 5 The EDX of No. 11 sample (a) outside weld (b) inside weld (c) parent tube (d) inner liner

Table 1 The EDX of No. 11 sample (wt.%)

| The part of analysis | C | Si | Cr | Fe | Ni | Mo |
|----------------------|-------|-------|-------|-------|-------|-------|
| Parent tube | 03.08 | 01.61 | 00.50 | 92.43 | 01.09 | – |
| Inner liner | 02.96 | 01.17 | 16.13 | 65.56 | 11.22 | 03.23 |
| Inside weld | 03.23 | 01.43 | 15.37 | 67.37 | 09.80 | – |
| Outside weld | 03.93 | 01.16 | 00.82 | 91.79 | 00.57 | – |

reduce the possibility of weld intergranular corrosion. The microstructure of outmost weld is hot-rolled state of ferrite with a small amount of pearlite. The grain in heat-affected zone is more crassitude than the base material, which is mainly due to the welding process of heating and cooling inhomogeneity and the heat-affected zone overheated. Metal impurities tend to segregate easily at coarse grain boundaries; therefore, the possibility of producing cracks is increasing [7].

Conclusions and Suggestions

- (1) Failure samples have no obvious signs of erosion, and the main reason of failure was weld corrosion caused by medium. Failure points are all located at the bottom of pipes, which are arc starting points.
- (2) The main failure modes of composite pipe butt weld are pitting corrosion, galvanic corrosion, stress corrosion, and crevice corrosion.

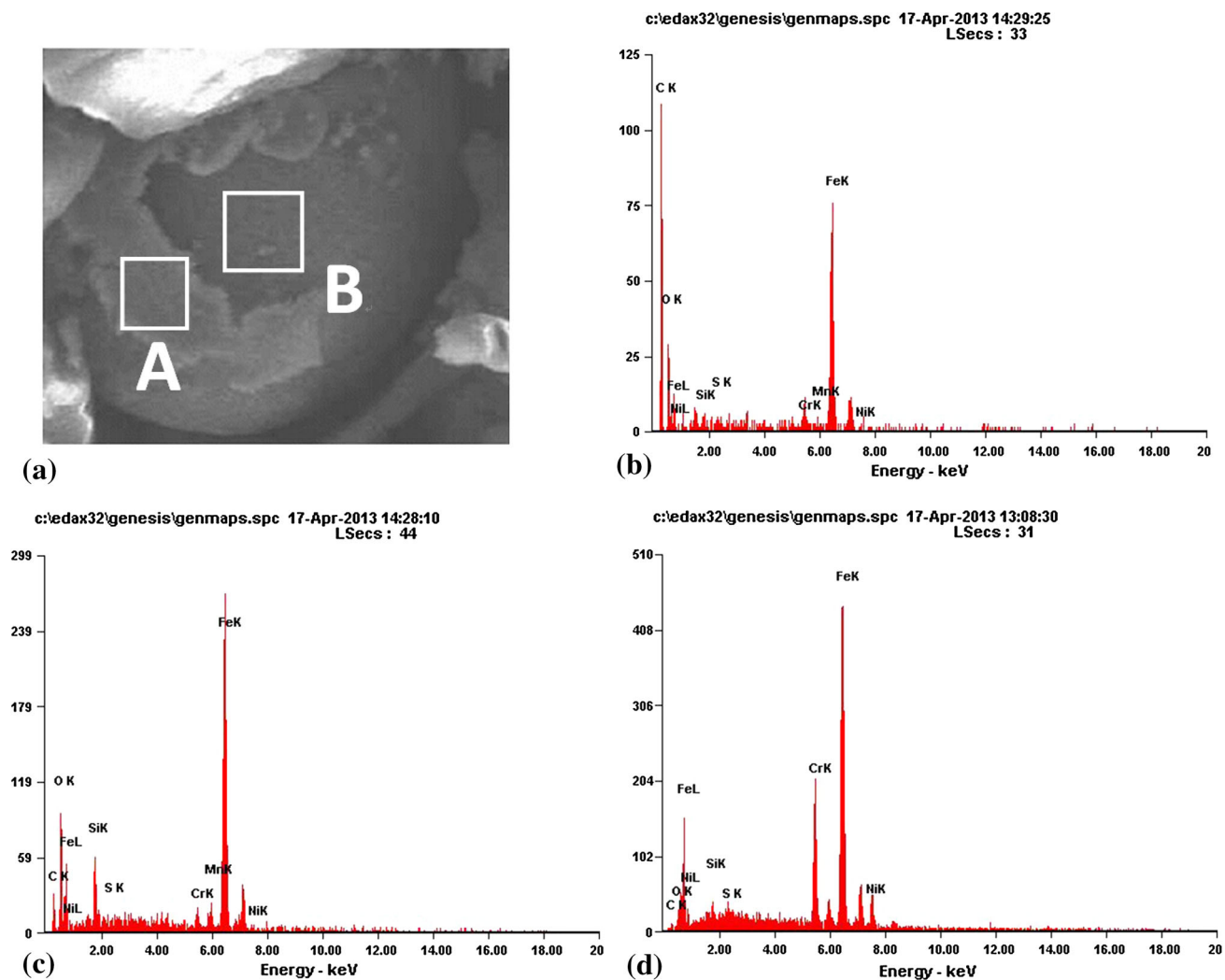


Fig. 6 The EDX of No. 17 sample (a) location of analysis (b) EDX of A area (c) EDX of B area (d) EDX of inside weld

Table 2 The EDX of No. 17 sample (wt.%)

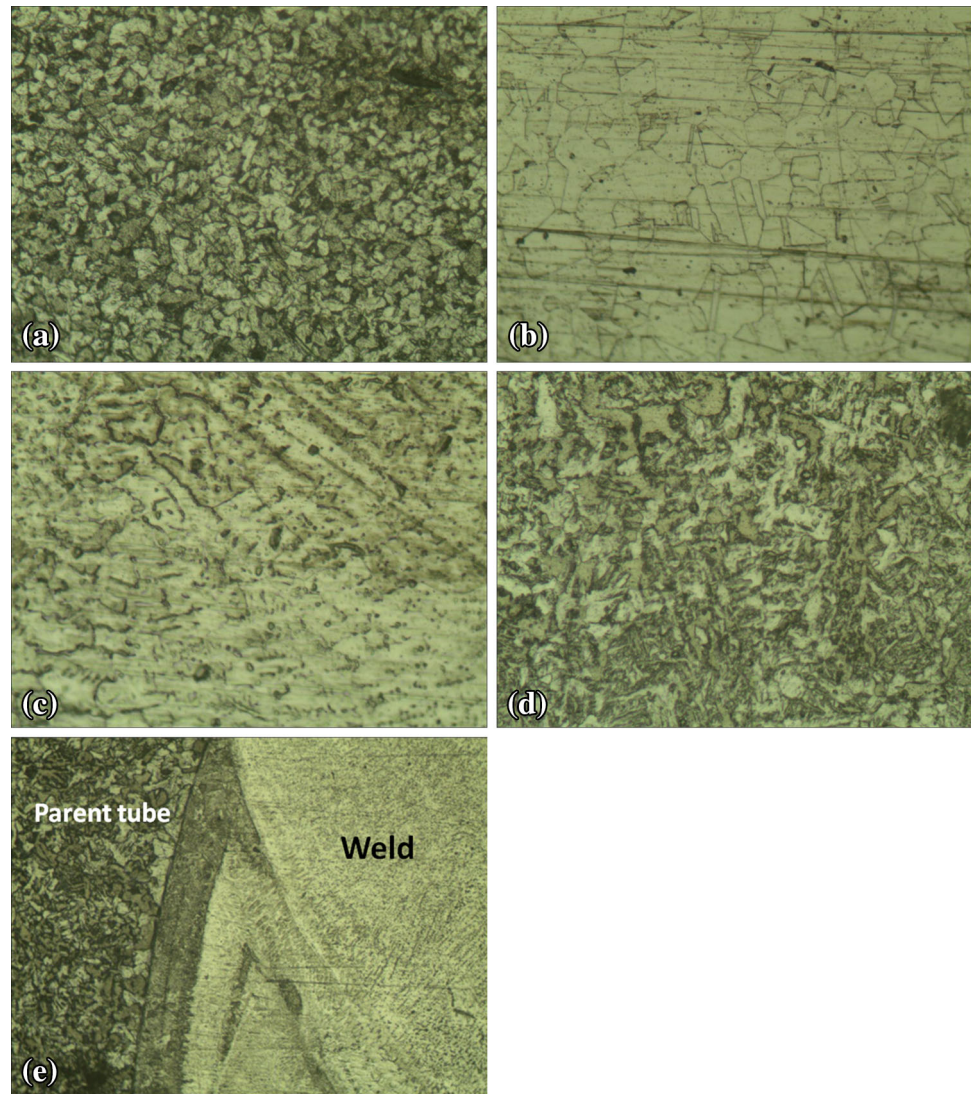
| The part of analysis | Si | Cr | Fe | Ni | O |
|----------------------|-------|-------|-------|-------|-------|
| A | 00.32 | 01.34 | 34.99 | ... | 11.63 |
| B | 03.59 | 01.83 | 62.03 | 00.44 | 12.63 |
| Inside weld | 01.43 | 15.37 | 67.37 | 09.80 | 01.60 |

- (3) EDX analysis result shows that there is no Mo element in inside and outside weld organization, therefore the corrosion resistance of weld material and the stability of passivation film have been decreased, and the occurrence of localized corrosion has been promoted.
- (4) The failure mechanism of composite pipe butt weld is the result of joint action of the gradual shedding of corrosion product films, workmanship, and quality of weld, the influence of the microstructure by welding residual stress and corrosive medium.

The composite pipe butt weld failure process is summarized as follows:

Welding is easy to produce welding slag, weld flash, and other rough protrusions on the inner surface of weld [10], so that such inner surface of weld can not form a continuous weld passivation film. Because the weld metal is short of Mo element, the weld surface can not form dense passivation film. The welding residual stress leads to passive films fell off. The passive films that fall off make the matrix exposed to the environment with Cl^- and generation pitting corrosion, thus lead to stress corrosion and cracks.

Fig. 7 The metallographic analysis results of No. 11 sample (a) parent tube, (b) inner liner, (c) inside weld, (d) outside weld, and (e) fusion line



Through the analysis of microstructure, the grain of weld and parent metal combination area is relatively bulky, and the sensitivity of stress corrosion is increased. The inevitable defects in welding process have induced effect to pitting corrosion, stress corrosion, and crevice corrosion [11]. The defects of weld zone and arcing point such as microcrack, incomplete fusion and burn through, which will cause stress concentration in these areas. The medium contains Cl^- gathered at the bottom of the pipe near the arcing point and exacerbating the spitting corrosion, stress corrosion, and crevice corrosion of weld. After the inner weld was penetrated due to corrosion, the base pipe and weld contacts to the fluid and form galvanic corrosion. Because the electrode potential of weld and carbon steel are different, the base pipe and weld forms galvanic corrosion. These reasons accelerated the pipeline failure until washout.

In view of the above-mentioned situations, the following measures should be taken to slow down the failure of composite pipe butt weld.

- (1) Control the content of alloying elements. Select welding materials that contain Ni, Mo, Cr, V, and other elements to achieve the purpose of improving the microstructure, and try to avoid losing beneficial elements (such as Mo) in the process of welding.
- (2) Control the condition of transmission medium. Reduce the concentration of the corrosive medium, raise the pH value of the medium, and reduce the operating temperature of medium. As the temperature rises, the crack propagation rate increases [12]. The increase of temperature could increase the chloride ion concentration [13], thus increasing the corrosion rate.

- (3) Improve the quality of welding. Improve the quality of arc starting points and the end of welding point.
- (4) Reduce the welding residual stress by improving welding procedures (i.e., Preheat, PWHT, etc.).

References

1. J. Gu, Use and production method of bimetallic clad steel tubes overseas. *Shanghai Iron* **22**(4), 16–24 (2000)
2. G. Xiao, Stainless steel, carbon steels multiple tube production technology. *Metall Sichuan* **1**, 58 (2000)
3. M.A. Spence, C.V. Roscoe, Bi-metal CRA-lined pipe employed for North Sea field development. *Oil Gas* **97**(18), 80 (1999)
4. S. LI, *Practical Technology of Long Distance Pipeline Welding* (Chemical Industry Press, Beijing, 2009), pp. 85–107
5. H. Chen, Analysis of well-head facilities failure. *Nat. Gas Ind.* **24**(7), 65–67 (2004)
6. G. Hu, C. Xu, X. Zhang, Composition and structure of the passive film of 304 stainless steel in an occluded solution. *J. Beijing Univ. Chem. Technol.* **30**(1), 20–23 (2003)
7. S. Jiang, *Failure Analysis of the Butt Weld of Bimetal Composite Pipes of 20G/316L* (Southwest Petroleum University, Chengdu, 2013)
8. Z. Wang, H. Xu, K. Guan et al., *Chemical Equipment Failure Theory and Case Analysis* (East China University of science and technology press, Shanghai, 2010)
9. H. Zang, Y. Zhang, Y. Zhou et al., Corrosion failure analysis of composite pipe welds. *Energy Conserv.* **7**, 23–26 (2010)
10. H. Chen, S. Jiang et al., Failure analysis of oil-gas transportation pipelines in a high temperature and high pressure gas field containing CO₂. *Corros. Prot.* **34**(2), 185–188 (2013)
11. X. Tan, *Study on Stresses and Strain of Steel Structure of Modern Architecture of Bolt and Weld* (Nanjing University of Science and Technology, Nanjing, 2012)
12. H. Asteman, J.E. Svensson, M. Norell, L.G. Johansson, Influence of water vapor and flow rate on the high-temperature oxidation of 304L effect of chromium oxide hydroxide evaporation. *Oxid. Met.* **54**(1–2), 11–26 (2000)
13. M. Zhagn, Chloride-induced stress corrosion cracking analysis of TP321H stainless steel pipeline. *Petro-Chem. Equip.* **39**(4), 100–102 (2010)