第六章 重大设备的失效分析

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目 录

6.1 核电装置的失效分析

6.2 火电装置的失效分析

6.3 风电设备的失效分析

6.4 石化装置的失效分析

6.5 化工设备的失效分析

6.6 冶金设备的失效分析

6.7 交通部件的失效分析

6.8 电子电路的失效分析

6.9 城市管网的失效分析

6.1 核电装置的失效分析

6.1.1 典型案例分析

1. 核电厂 RCW热交换器传热钛管的失效分析与治理方案
2. 核电厂凝汽器钛管异常减薄的失效分析与解决对策
3. 核电厂汽轮机EH系统油动机密封圈意外泄漏的失效分析
4. 核电厂乏燃料储存水闸门减速器异常断裂的失效分析
5. 核电厂消氢系统工艺管道泄漏的失效分析与解决方案
6. 核电厂汽轮机系统循环水泵地脚螺栓异常断裂的失效分析
7. 核电厂汽轮机系统凝升泵角接触滚子轴承的失效分析
8. 核电厂循环水泵闸阀驱动杆异常断裂的失效分析
9. 核电厂核岛硼酸再循环泵转动轴意外断裂的失效分析
10. 核电厂冷却循环水泵磨损的失效分析与解决对策
11. 不同辐照剂量对核电电缆材料性能的影响分析及评价
12. 核电厂用缠绕式换热器异常爆裂的失效分析

6.1 核电装置的失效分析

13. 不同辐照剂量对核电用电缆材料的性能影响分析
14. 主泵径向止推轴承室O形密封圈的失效分析与解决对策
15. 先进压水堆蒸汽发生器管板储存过程中腐蚀失效分析与及预防
16. 核电回路系统缠绕管换热器异常泄漏的失效分析
17. 核电站变压器用继电器浮球的失效分析

6.1.2 主要参考文献

1. Zhen-Guo Yang*, Yi Gong, Jian-Zhong Yuan. Failure analysis of leakage on titanium tubes within heat exchanger in a nuclear power plant. Part I: Electrochemical corrosion. Materials and Corrosion, 2012, 63 (1): 7-17.
2. Yi Gong, Zhen-Guo Yang*, Jian-Zhong Yuan. Failure analysis of leakage on titanium tubes within heat exchanger in a nuclear power plant. Part II: Mechanical degradation Materials and Corrosion, 2012, 63 (1): 18–28.

6.1 核电装置的失效分析

3. Fei-Jun Chen, Chen Yao, Zhen-Guo Yang*. Failure analysis on abnormal of heat-transfer titanium tubes of condensers in nuclear power plant Part I: corrosion and wear. Engineering Failure Analysis, 2014, 37: 29-41.

4. Fei-Jun Chen, Chen Yao, Zhen-Guo Yang*. Failure analysis on abnormal wall thinning of heat-transfer titanium tubes of condensers in nuclear power plant PartII: erosion and cavitation corrosion. Engineering Failure Analysis, 2014, 37: 42-52.

5. Xiao-Lei Yang, Qun Ding, Zhen-Guo Yang*. Failure analysis of O-ring gasket of electric hydraulic system in nuclear power plant. Engineering Failure Analysis, 2017, 79: 232–244.

6. Tong-Tong Bi, Zhen-Guo Yang*. Failure analysis on speed reducer shaft sluice gate in nuclear power plant. Engineering Failure Analysis, 2017, 80: 453-463.

6.1 核电装置的失效分析

7. Yi Gong, Shi-Meng Hu, Jing-Lu Fei, Xiao-Lei Yang, Zhen-Guo Yang* Ai-Hua Guo, Xiu-Qiang Shi, Yong-Cheng Xie. Comparative study on degradation of ethylene-propylene rubber for nuclear cables from gamma and beta irradiation. Polymer Testing, 2017, 60: 102-109.

8. Qun Ding，Zhen-Guo Yang*，Hong-Lian Zheng, Xiao Lou. Failure analysis on abnormal leakage of TP321 stainless steel pipe in hydrogen-eliminated system of nuclear power plant. Engineering Failure Analysis, 2018, 89: 286-292.

9. Tong-Wei Ni，Qun Ding，Zhen-Guo Yang*, Hong-Lian Zheng, Xiao Lou. Failure analysis on premature fracture of boric acid recycle pump shaft in 1000 MW nuclear power plant. Engineering Failure Analysis, 2018, 92: 317-326.

10. Yi Gong, Qun Ding，Zhen-Guo Yang*. Failure analysis on premature fracture of anchor bolts in seawater booster pump of nuclear power plant. Engineering Failure Analysis, 2019, 97: 10-19.

6.1 核电装置的失效分析

11. Yi Gong, Jie Tang, Bei-Ni Sun, Zhen-Guo Yang*, Xiu-Qiang Shi, Xiao-Qiang Liu, Yong-Cheng Xie, Xue-Lian Xu. Comparative study on different methods for determination of activation energies of nuclear cable materials, Polymer Testing, 2018, 70: 81-91.

12. Yi Gong, Fu-Qiu Ma, Yun Xue, Cai-Shan Jiao, Zhen-Guo Yang*. Failure analysis on leaked titanium tubes of seawater heat exchangers in recirculating cooling water system of coastal nuclear power plant. Engineering Failure Analysis, 2019, 101: 172-179.

13. Yi Gong, Jie Tang, Xiao-Lei Yang, Zhen-Guo Yang*, Xiu-Qiang Shi, Yong-Cheng Xie, Ai-Hua Guo, Jian-Feng Xu. Effect of irradiation dose rates on ethylene-propylene rubber for nuclear cables. Applied Surface Science, 2019, 484: 845-852.

14. Xiao-Lei Yang, Sheng-Hui Wang, Yi Gong, Zhen-Guo Yang*. Failure analysis on abnormal bursting of heat transfer tubes in spiral-wound heat exchanger for nuclear power plant. Engineering Failure Analysis, 2020, 107: 166-179.

6.1 核电装置的失效分析

15. Yi Gong, Ming-Ying Du, Fu-Qiu Ma, Guang-Qing He, Yun Xue, Cai-Shan Jiao, Xiao-Lei Yang, Rong-Bo Li, Zhen-Guo Yang*. Failure analysis and prevention of corrosion occurring during storage on steam generator tube sheet for advanced PWR, Part I: root causes analysis. Engineering Failure Analysis, 2020, 115: 104710.

16. Yi Gong, Ming-Ying Du, Guang-Qing He, Zhen-Guo Yang*, Rong-Bo Li, Xiao-Jun Li, Cai-Lin Jiang, Xiao-Qiang Liu , Xue-Lian Xu, Ai-Hua Guo. Failure analysis and prevention of corrosion occurring during storage on steam generator tube sheet for advanced PWR, Part II: corrosion prevention design. Engineering Failure Analysis, 2020, 115: 104688.

17. Yi-Min Mo， Yi Gong， Zhen-Guo Yang*. Failure analysis on the O-ring of radial thrust bearing room of main pump in a nuclear power plant. Engineering Failure Analysis, 2020, 115: 104673.

6.1 核电装置的失效分析

18. Xiao-Lei Yang, Yi Gong, Zhen-Guo Yang*. Failure analysis on abnormal leakage between tubes and tubesheet of spiral-wound heat exchanger for nuclear power plant. Engineering Failure Analysis, 2020, 118: 104900.

6.2 火电装置的失效分析

6.2.1 典型案例分析

1. 超超临界1000MW火电机组循环水泵断裂的失效分析
2. T91钢管异种钢焊接工艺评定与寿命评估
3. 超超临界机组T92/HR3C异种钢焊接蠕变寿命评定
4. 超超临界机组T92/Super304异种钢焊接性能评定
5. 锅炉二次过热器后屏炉管的腐蚀失效分析
6. 600MW火电机组电动机SKF滚动轴承的失效分析
7. 汽轮机EH系统油动机螺栓断裂的失效分析
8. 汽轮机DEH系统电液伺服阀异常堵塞的失效分析

6.2.2 主要参考文献

1. Yue-Yue Ma, Shi Yan, Zhen-Guo Yang*, Guo-Shui Qi, Xin-You He. Failure analysis on circulating water pump of duplex stainless steel in 1000 MW ultra-supercritical thermal power. Engineering Failure Analysis, 2015, 47: 162-177.

6.2 火电装置的失效分析

2. Jian Cao, Yi Gong, Zhen-Guo Yang*. Microstructural analysis on creep properties of dissimilar materials joints between T92 martensitic and HR3C austenitic steels. Materials Science and Engineering A, 2011, 528: 6103-6111.
3. Zhi-Qiang Yu, Zhen-Guo Yang. Analysis of fatigue fracture on the outer ring of a cylindrical roller bearing in an air blower motor. Journal of Failure Analysis and Prevention, 2012, 12(4) : 427–437.
4. Jian Cao, Yi Gong, Kai Zhu, Zhen-Guo Yang*，Xiao-Ming Luo, Fu-Ming Gu. Microstructure and mechanical properties of dissimilar materials joints between T92 martensitic and S304H austenitic steels. Materials and Design, 2011, 32(5): 2763-2770.
5. Yi Gong, Zhen-Guo Yang*. Corrosion evaluation of one dry desulfurization equipment — circulating fluidized bed boiler. Materials and Design, 2011, 32(1): 671-681.

6.2 火电装置的失效分析

6. Jian Cao, Yi Gong, Zhen-Guo Yang*, Xiao-Ming Luo, Fu-Ming Gu, Zheng-Fei Hu. Creep fracture behavior of dissimilar weld joint between T92 martensitic and HR3C austenitic steels. International Journal of Pressure Vessel and Piping, 2011, 88: 94-98.

7. Zheng-Fei Hu, Zhen-Guo Yang.* An investigation of the embrittlement in X20CrMoV12.1 power plant steel after long-term service exposure at elevated temperature. Materials Science and Engineering A, 2004, 383(2)： 224-228.

8. Zhi-Qiang Yu, Zhen-Guo Yang. Fatigue failure analysis of a grease-lubricated roller bearing from an electric motor. Journal of Failure Analysis and Prevention, 2011, 11(2) : 158–166.

6.2 火电装置的失效分析

9. Tong-Wei Ni, Zhen-Guo Yang*. Failure analysis on unexpected leakage of electro-hydraulic servo valve in digital electric hydraulic control system of 300 MW thermal power plant. Engineering Failure Analysis, 2021, 119: 104992.

10. Sheng-Hui Wang, Tong-Wei Ni, Zhen-Guo Yang*. Failure analysis on abnormal blockage of electro-hydraulic servo valve in digital electric hydraulic control system of 125 MW thermal power plant. Engineering Failure Analysis, 2021, 123: 105294.

6.3 风电设备的失效分析

6.3.1 典型案例分析

1. 海上4MW风电设备变压器超温燃烧的失效分析
2. 1.5MW风电设备齿轮箱轴承异常磨损的失效分析

6.3.2 主要参考文献

1. Yi-Min Zhu, Yi Gong, Zhen-Guo Yang*. Root cause analysis on over-temperature combustion of transformers in 4 MW offshore wind turbines. Engineering Failure Analysis, 2019, 96: 211-222.
2. Yi Gong, Zhen-Guo Yang*, Yong-Ming Han, Pei-Zhong Liu, Xiang Li. Failure analysis on abnormal wear of roller bearings in gearbox for wind turbine. Engineering Failure Analysis, 2017, 82: 26-38.

6.4 石化装置的失效分析

6.4.1 典型案例分析

1. 年产109万吨聚乙烯装置急冷油/稀释蒸汽换热器管子的腐蚀失效分析
2. 高压聚乙烯装置循环气体冷却器爆裂的腐蚀失效分析
3. PTA聚酯装置干燥器的失效分析及其解决对策
4. 加氢精制PTA聚酯装置的失效分析及治理方法
5. 大型萃取塔MMA内壁异常磨损的失效分析
6. 石化装置受火损伤后HDPE管道的试验分析与寿命评定
7. 制氢装置中变气管不锈钢管道应力腐蚀开裂的失效分析
8. MMA萃取塔的失效分析及预防-安全设计模式的应用

6.4 石化装置的失效分析

6.4.2 主要参考文献

1. Yi Gong, Zhen-Guo Yang*, Xin-Hao Meng. Failure analysis of one peculiar 'Yin-Yang' corrosion morphology on heat exchanger tubes in purified terephthalic acid (PTA) dryer Engineering Failure Analysis, 2013, 31: 203-210.

2. Yi Gong, Chao Yang，Cheng Yao，Zhen-Guo Yang*. Acidic/caustic alternating corrosion on carbon steel Pipes in heat exchanger of ethylene plant. Materials and Corrosion, 2011, 62(10): 967-978.

3. Yi Gong, Jing Zhong, Zhen-Guo Yang*. Failure analysis of bursting on the inner pipe of a jacketed pipe in a tubular heat exchanger. Materials and Design, 2010, 31(9): 4258-4268.

6.4 石化装置的失效分析

4. Yi Gong , Jiang Cao, Xin-Hao Meng, Zhen-Guo Yang*. Pitting corrosion on 316L pipes in terephthalic Acid (TA) dryer. Materials and Corrosion, 2009, 60 (11)： 899-908.

5. Jing-Lu Fei , Xiao-Lei Yang, Sheng-Hui Wang, Yi Gong, Jun Wang, Xin Tao, Zhen-Guo Yang*. Failure analysis and countermeasures on localized abnormal wear of MAA extraction column. Engineering Failure Analysis, 2019, 100: 166-179.

6. Si-Min Guo, Zhen-Guo Yang*, Xiao-Ying Tang， Yan-Tian Zhu. Safety assessment of high density polyethylene pipe with thermal damages. Plastics, Rubber and Composites: Macromolecular Engineering, 2017, 46(4): 173-183.

6.4 石化装置的失效分析

7. Yi Gong, Xiao-Lei Yang， Sheng-Hui Wang, Zhen-Guo Yang*. Failure analysis on leaked jacket pipe of double-pipe heat exchanger in high-pressure polyethylene facility. International Journal of Pressure Vessels and Piping, 2020, 187: 104166.

8. Jie Chen, Yi Gong, Tong-Hao Jiang, An-Xia Pan, Sheng-Hui Wang, Zhen-Guo Yang*. Failure analysis on abnormal leakage of TP321 stainless steel pipe of medium temperature shifting gas in hydrogen production system. Engineering Failure Analysis, 2021, 125: 105413.

9. Sheng-Hui Wang, Yi Gong, Qi Tong, Xiao-Lei Yang, Jia-Hao Shen, Zhen-Guo Yang*. Failure analysis and prevention of extraction column for methyl methacrylate production: application of the ‘safety design’ concept. Materials. 2021, 14: 4234.

6.5 化工设备的失效分析

6.5.1 典型案例分析

1. 废热锅炉系统低温省煤器腐蚀泄漏的失效分析与治理方案
2. 氨气蒸发器换热管壁厚异常减薄的失效分析
3. 高硫含量循环流化床锅炉设备的腐蚀失效分析
4. 腐蚀条件下设备防腐蚀材料的制备与分析
6. 化工厂蒸汽系统管配件的腐蚀失效分析
7. 化工厂塔釜再沸器异常泄漏的失效分析
8. 冲刷腐蚀作用下T型管异常泄漏的失效分析与解决对策
9. 精致盐蒸发罐异常泄漏的失效分析与整改方案

6.5.2 主要参考文献

1. Qun Ding, Xiao-Feng Tang，Zhen-Guo Yang*. Failure analysis on abnormal corrosion of economizer tubes in a waste heat boiler. Engineering Failure Analysis, 2017, 73: 129-138.

6.5 化工设备的失效分析

2. Shi-Meng Hu, Sheng-Hui Wang, Zhen-Guo Yang*. Failure analysis on unexpected wall-thinning of heat exchange tubes in ammonia evaporator. Case Studies in Engineering Failure Analysis, 2015, 3: 52-61.

3. Yi Gong, Zhen-Guo Yang*. Corrosion evaluation of one dry desulfurization equipment — circulating fluidized bed boiler. Materials and Design, 2011, 32(2): 671-681.

4. Lan-Hui Sun, Zhen-Guo Yang*, Xiao-Hui Li. Study on the friction and wear behavior of POM/ Al2O3 nanocomposites. Wear，2008，264(7)：693-700.

5. Yu-Fei Wang, Zhen-Guo Yang*. Finite element model of erosive wear on ductile and brittle materials. Wear, 2008, 265 (5): 871-878.

6.5 化工设备的失效分析

6. Jing-Lu Fei, Xiao-Lei Yang, Sheng-Hui Wang, Yi Gong, Zhen-Guo Yang*. Failure analysis and countermeasures on unexpected perforation of tee pipe in the steam system of specialty chemical plant. Engineering Failure Analysis, 2019, 104: 796-806.

7. Xiao-Lei Yang, Jing-Lu Fei, Sheng-Hui Wang, Yi Gong, Zhen-Guo Yang*. Failure analysis on abnormal corrosion of pipe fittings of steam system in specialty chemical plant Part I: Elbows. Materials and Corrosion, 2019, 70(5): 906-920.

8. Xiao-Lei Yang, Sheng-Hui Wang, Jing-Lu Fei, Yi Gong, Zhen-Guo Yang*. Failure analysis on synergistic effect of erosion and corrosion on failed fittings in specialty chemical plant Part II: control valve. Materials and Corrosion, 2019, 70(5): 921-929.

6.5 化工设备的失效分析

9. Zhen-Guo Yang* and Yi Gong. Chapter 16 Failure analysis of heat exchanger tubes in petrochemical industry: microscopic analysis approach. Handbook of Materials Failure Analysis. Elsevier, 2016: 329-352.

10. Chun-Xiang Shi, Yi Gong, Zhen-Guo Yang, Qi Tong. Peridynamic investigation of stress corrosion cracking in carbon steel pipes. Engineering Fracture Mechanics. 2019, 219: 106604.

11. Tong-Wei Ni, Jing-Lu Fei, Sheng-Hui Wang, Yi Gong, Zhen-Guo Yang*. Failure analysis on unexpected perforation of heat exchanger tube in methacrylic acid reboiler of specialty chemical plant. Engineering Failure Analysis, 2020, 107: 32-43.

6.6 冶金设备的失效分析

6.6.1 典型案例分析

1. 高炉炼焦气燃气轮机叶片的腐蚀断裂分析
2. 蠕变温度下耐热钢的碳化物析出表征及老化分析
3. 二次过热器炉管的腐蚀失效分析及对策
4. 炼铁厂起堆料机异常腐蚀的失效分析与防护方法

6.6.2 主要参考资料

1. Yi Gong, Zhen-Guo Yang*, Fa-Yun Yang. Heat strength evaluation and microstructures observation of the welded joints of one China-made T91 steel. Journal of Materials Engineering and Performance, 2012, 21(7): 1313-1319.

2. Kai Zhu, Jian Yang, Rui-zhi Wang, Zhen-Guo Yang*. Effect of Mg addition on inhibiting austenite grain growth of Ti-bearing low carbon steels. Journal of Iron and Steel Research International, 2011, 18(9): 60-64.

6.6 冶金设备的失效分析

3. Zheng-Fei Hu, Zhen-Guo Yang *. Identification of the precipitates by TEM and EDS in X20CrMoV12.1 for long-term service at elevated temperature. Journal of Materials Engineering and Performance, 2003, 12 (1): 106-111.

4. Kai Zhu, Zhen-Guo Yang*. The Effect of magnesium on the austenite grain growth of the heat affected zone in low carbon steels. Metallurgical and Materials Transaction A, 2011, 42(8): 2207-2213.

5. Kai Zhu, Zhen-Guo Yang*. Effect of Mg Addition on the Ferrite grain boundaries microorientation in HAZ of low carbon steels. Journal of Materials Science & Technology, 2011, 27(3): 252-256.

6. Wei-Ming Guo, Zhen-Guo Yang*, Guo-Jun Zhang*. Effect of carbon impurities on hot-pressed ZrB2-SiC ceramics. Journal of the American Ceramic Society, 2011, 94(10): 3241–3244.

6.7 交通部件的失效分析

6.7.1 典型案例分析

1. 汽车油门加速器用复合材料踏板断裂的失效分析
2. 汽车用复合材料密封件的力学性能分析与评价
3. 摩托车减震弹簧异常断裂的失效分析
4. 轨道车辆用橡胶球关节的失效分析
5. 高速列车变压器用散热器异常腐蚀泄漏的失效分析
6. 地铁齿轮箱吊杆过早断裂的原因分析
7. 高铁用齿轮箱油位计玻璃板的失效分析和解决对策
8. 汽车用碳纤维缠绕铝合金储氢瓶疲劳试验泄漏的失效分析
9. 列车制动盘弹性销开裂的失效原因分析
10. 转向架齿轮箱不同类型滚动轴承的失效分析
11. 转向架感应器弹性体挡板异常断裂的失效分析

6.7 交通部件的失效分析

6.7.2 主要参考文献

1. Yi Gong, Zhen-Guo Yang*. Fracture failure analysis of automotive accelerator pedal arms with polymer matrix composite material . Composites B, 2013, 53: 103-111.

2. Bo-Chao Liu, Zhen-Guo Yang. Failure analysis of shock absorption spring in motorcycle. Journal of Failure Analysis and Prevention, 2016, 16(2): 337-345.

3. Yu-Qi Qin, Yi Gong, Yi-Wen Yuan, Zhen-Guo Yang*. Failure analysis on leakage of hydrogen storage tank for vehicles occurring in oil circulation fatigue test. Engineering Failure Analysis, 2020, 117: 104830.

6.7 交通部件的失效分析

4. Lan-Hui Sun, Zhen-Guo Yang*, Xiao-Hui Li. Effects of the treatment of attapulgite and filler contents on tensile properties of PTFE and attapulgite reinforced fabric composites. Composites A, 2009，40 (11): 1785-1791.

5. Qian-Shu Lu, Lan-Hui Sun, Zhen-Guo Yang*, Xiao-Hui Li, Shi-Lan Jin. Optimization on the thermal and tensile influencing factors of polyurethane-based polyester fabric composites. Composites A, 2010, 41(8): 997-1005.

6. Chang Su, An-Xia Pan, Yi Gong, Zhen-Guo Yang*. Failure analysis on rubber universal spherical joints for rail vehicles. Engineering Failure Analysis, 2021, 126: 105453.

7. An-Xia Pan， Yi Gong , Zhen-Guo Yang*. Failure analysis on abnormal leakage of radiator for high-speed train transformer. Engineering Failure Analysis, 2021, 129: 105673.

8. Undisclosed several failure analysis reports by Fudan University.

6.8 电子电路的失效分析

6.8.1 典型案例分析

1. 芯片引线框架高速电镀不锈钢钢带的失效分析
2. 手机用BGA焊点及盲孔开裂的失效分析

6.8.2 主要参考文献

1. Yun-Song Gu, Yi Gong, Zhen-Guo Yang*. Hydrogen Embrittlement on High-speed Stainless Steel Belts Used for Tin Plating Chip Lead Frame.
   Journal of Failure Analysis and Prevention, 2010, 10(5): 399-407.
2. Li-Na Ji, Zhen-Guo Yang*, Jian-Sheng Liu. Failure analysis on blind vias of PCB for novel mobile phones. Journal of Failure Analysis and Prevention, 2008, 8(6) : 524-532.

6.8 电子电路的失效分析

6.8.3 典型案例分析

1. 高密度PCB电镀铜互连盲孔的失效分析
2. PCB表面处理ENIG未浸润的失效分析
3. PCB 引线键合及钎焊电镀镍金表面处理的失效分析
4. 高端智能手机用PCB及PCBA的失效分析

6.8.4 主要参考文献

1. Fei-Jun Chen, Shi Yan, Zhen-Guo Yang*. Failure Analysis on Electrolytic Ni/Au Surface Finish of PCB Used for Wire Bonding and Soldering. Soldering & Surface Mount Technology, 2014, 26(4): 180–193.
2. Li-Na Ji, Yi Gong, Zhen-Guo Yang*. Failure Investigation on Copper-plated Blind Vias in PCB. Microelectronics Reliability, 2010, 50 (8): 1163-1170.

6.8 电子电路的失效分析

3. Shi Yan, Fei-Jun Chen, Yue-Yue Ma, Zhen-Guo Yang*. Failure analysis of un-wetting for the surface finish on the ENIG. Journal of Failure Analysis and Prevention, 2013, 13(2): 194-201.

4. Jie Tang, Yi Gong, Zhen-Guo Yang*. Failure analysis on cracking of blind and buried vias of printed circuit board for high-end mobile phones. Soldering & Surface Mount Technology, 2019, 31(4): 203-210.

6.9 城市管网的失效分析

6.9.1 典型案例分析

1. 地铁附近埋地Dn1000管线异常泄漏的腐蚀失效分析
2. 冲刷腐蚀工况下不同管道的失效机理与预防方法
3. 城市天然气管网埋地HDPE管泄漏的失效分析

6.9.2 主要参考文献

1. Tong-Wei Ni, Tong-Tong Bi, Zhen-Guo Yang*. Failure analysis on abnormal perforation of super large diameter buried gas pipeline nearby metro. Engineering Failure Analysis, 2019, 103: 32-43.

2. Yu-Fei Wang, Zhen-Guo Yang*. Finite element analysis of residual thermal stress in ceramic lined composite pipe prepared by centrifugal-SHS. Materials Science and Engineering A，2007，460(5): 130-134.

6.9 城市管网的失效分析

3. Xiao-Lei Yang，Sheng-Hui Wang，Yi Gong，Zhen-Guo Yang*. Effect of biological degradation by termites on the abnormal leakage of buried HDPE pipes for urban gas distribution networks. Engineering Failure Analysis, 2021, 124: 105367.

第六章 思考题

1. 概述引进的重水堆核电装置RCW热交换器钛管异常泄漏的失效分析主要分析步骤。哪些方法对该复杂案例分析运用得相当精准?
2. 在对进口的超超临界1000MW火电机组循环水泵发生过早失效的案例分析中，泵体接管的设计与制造存在哪些隐患？应如何改进?
3. 试从风电设备两个失效案例中，安装过程应该吸取哪些教训?
4. 通过对引进的石化装置PTA干燥器的失效分析，简述设备在检修与维护过程中须应注意哪些安全因素?
5. 化工设备一般存在冲刷与腐蚀的交互作用工况，从安全角度应如何选材及防护？就弯管而言，采用什么方法可抑制这种复杂的失效?
6. 在冶炼设备的失效分析案例中，控制哪些因素可以避免燃气轮机叶片发生过早失效呢?
7. 在对汽车纤维增强树脂复合材料踏板开展的失效分析过程中，复合材料构件最易发生哪些类型的失效？产生的原因主要有哪些?
8. 微电子元器件都要进行表面处理，从芯片引线框架高速电镀到芯片贴装表面回流焊的失效案例中，必须认真应对哪些工艺环节?
9. 印制电路板是一种层状复合材料，试从高密度互连PCB的失效案例中概述PCB的主要失效形式？影响产品质量的因素一般有哪些 ?