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Experimental and theoretical aspects of crack assisted failures of metallic alloys in corrosive environments – A review

Ibrahim M. Alqahtani *, Andrew Starr, Muhammad Khan

School of Aerospace, Transport and Manufacturing, Cranfield University, Bedford MK43 0AL, UK

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ABSTRACT

Failure analysis is one of the complex tasks in engineering materials since it involves analyses of the interdependency of factors like environmental conditions, materials properties and loading conditions etc., causing catastrophic failure of engineering components in real-time applications. In recent times, the advances in characterization techniques have led to the precise findings of the cause of the failures in several cases. However, specific failure analysis-based case studies report that the couple load effects of two or more parameters influencing the failures of engineering components are complex to identify. Moreover, it is difficult to formulate a mathematical model involving the interdependency factors to study the failure behaviour of the engineering materials. Especially in aerospace industry, the crack initiation and propagation in metallic alloys are more complex since the various factors like environmental conditions combined with loading parameters cause unpredictable failures. Hence, there is a need to study the effect of environmental conditions combined with different loading systems on the crack propagation of metallic alloys. The review concludes that still a comprehensive analytical modelling approach is required to relate the interdependencies of couple loads such as humidity and temperature of metallic alloys in corrosive environment.

1. Introduction

Aggressive environments like ambient temperature fluctuations, humidity variations and environmental conditions play a crucial role in the environment assisted cracking of engineering materials. In addition, the combination of parameters like stress, material properties and environmental conditions is often causing the catastrophic failures in metallic alloys [1,2]. Especially materials under the influence of high temperature and humid conditions/water exposure are prone to crack initiation by corrosion phenomena like pit formation and then crack propagation. The material exposed to humid conditions/water exposure and high temperature give rise to oxide scale formations and further spallation of the same, leading to the new surface of the system undergoing further corrosion. These phenomena enhance the chances of crack initiation and influence the higher crack growth rate when both temperature and the environmental conditions combined affect the performance of the metallic alloy [3,4]. The published research has comprehensively investigated the influence of environmental and mechanical loads on crack assisted failures [5,6]. Stress corrosion cracking and hydrogen embrittlement are the most common ones which are observed and reported. However, most of the existing research efforts have reported empirical results only. Still efforts are required to model the relationship between the coupled environmental and mechanical load conditions with the material crack growth phenomenon [7-10]. Therefore, it is necessary to review the crack assisted failures of metallic alloys in terms of materials properties, environmental conditions, and different loading systems. In this paper, past empirical efforts are critically discussed to identify the challenges and gaps with regards to the mentioned model development.

2. Mapping of experimental works and results as a review

2.1. Corrosion assisted cracking

Environment assisted failure behaviour of aluminum-based alloys have been studied systematically in recent times. The con-

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* Corresponding author.
E-mail address: i.alqahtani@cranfield.ac.uk (I.M. Alqahtani).

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cerned outcome publishes the mechanism of corrosion assisted crack nucleation in the aforementioned alloys related to pitting corrosion, localized corrosion, anodic dissolution in an alloy matrix. The humidity factor is the predominant one in corrosion occurrence in these alloys. The crack growth studies correlate the crack growth factors to the hydrogen embrittlement and grain boundary effects.

The effect of environmental humidity on the failure behaviour of certain aluminum alloys is studied and inferred that relative humidity (RH) plays a crucial role in the crack propagation as shown in Fig. 1. Humidity assisted corrosion in aluminum alloys directly refers to the galvanic corrosion leading to pitting in the alloy matrix, where anodic dissolution is a significant phenomenon causing the pitting. Therefore, the indicating results in aluminum-based alloys focus on the anodic dissolution as one of the major influencing factors for crack initiation and propagation. In addition, the heat treatment procedures employed to enhance the mechanical properties introduce secondary phase precipitations in the alloy. Therefore, a significant alteration in the topographical response of the alloys to aggressive chemical environments is observed. This promotes the environmental assisted failures in aluminum-based alloys during engineering applications [7,11–14].

The study on the sensitiveness of some of the recent aluminium based alloys to hydrogen environment in promoting the crack initiation and prorogation at various stress levels ranging from low to high, is another important research domain in the analysis of corrosion assisted failures. In addition, various microstructural features are correlated to the failure mechanisms under the hydrogen environment. It is observed that even the lower stress factors are causing the crack propagation in metallic alloys like aluminium alloys, despite the absence of high stress level factors.

Fig. 2 shows the grain boundary cohesive energy variation for the hydrogen gas pressure, indicating that the grain boundaries stability depends on the hydrogen pressure to which the metallic material is exposed. In addition, some of the alloys show failure behaviour by crack propagation promoted by the presence of triple joints at the matrix of the alloy and direction oriented grain boundaries [15–18].

2.2. Measuring techniques in crack assisted failures

A systematic investigation on presently existing sustainable measuring techniques for the crack propagation analysis in metallic alloys under environmental conditions is essential as per the failure analysis studies carried out in the USA's defence related domains. In addition, the effect of various influencing factors like mixed and complex loading systems, aggressive environmental conditions, specific alloy properties and the couple load effect of the aforementioned factors on the failure mechanisms need to be considered while proceeding with the failure mechanism analysis. Several conventional techniques to measure the crack propagation related factors involve immersing the specimen in an electrolyte or exposing the specimen to constant humid conditions. However, these studies are inferior in predicting the real-time conditions of humidity assisted adhesive droplets adhering to the surface of the alloy products. As a result, the particular region based corrosion (Galvanic corrosion) leads to pitting and localised corrosions.

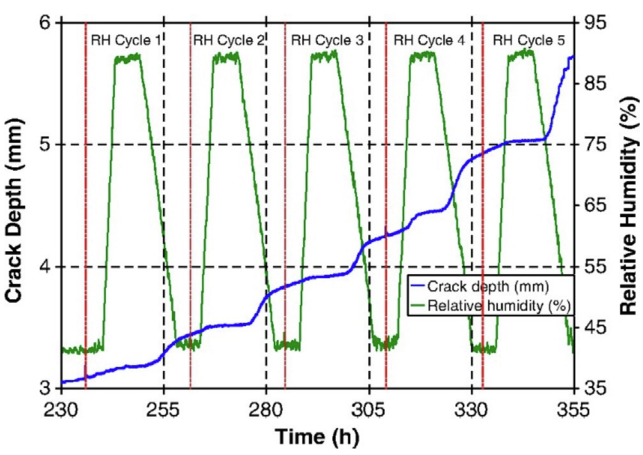

Fig. 1. AA5083 crack propagation under cyclic RH [7].

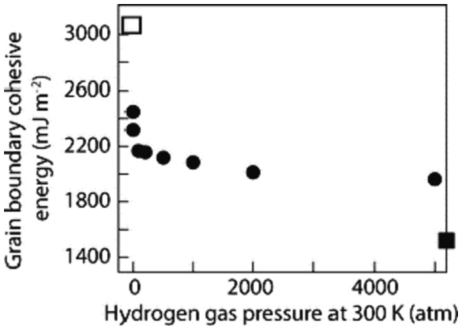

Fig. 2. Grain boundary cohesive energy as a function of hydrogen gas pressure [15].

Hence it necessitates studying the corrosion assisted failure behaviour namely the continuous crack propagation under in situ conditions. In this regard, tensile load notched specimen under static loading system, exposed to variable humidity conditions set up, can be subjected to predetermined loading cycles. This will enable the assessment of the crack propagation related factors like crack velocity shown in Fig. 3 and crack depth etc., in real-time environmental exposure conditions [7,19–21].

In general, the studies on the failure behaviour of metallic alloys comprise both experimental and theoretical analysis to validate the experimental data and predict the deformation behaviour of designed structural elements under environmental conditions. Therefore, the essentiality of carrying out a modelling study on the crack propagation assisted failures under corrosive environments to bring forth the theoretical correlation part to be executed simultaneously along with experimentations [22,23].

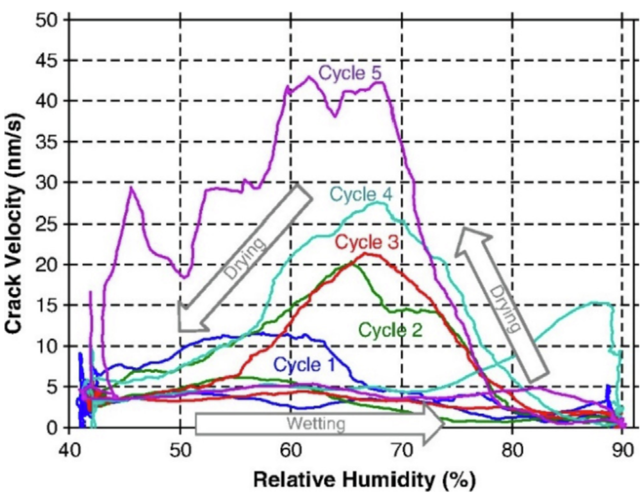

Fig. 3. AA5083 crack velocity vs. RH under cyclic RH testing [7].

2.3. Theoretical aspects of crack propagation and the corrosion parameters in metallic alloys

In the theoretical aspects of the failure behavioural studies of metallic alloys, the crack propagation rate, and Linear Elastic Fracture Mechanics Factor (LEFMF), K are the basic parameter to be considered. The primary measure of the effect of the load on crack growth is known as a stress intensity factor (SIF) and as it is determined by using Eq. (1).

$$K = Y\sigma\sqrt{\pi a} \tag{1}$$

K_{IC} is the more generally tensile load case for accessing the crack propagation. The Griffith's Criteria for tensile is given by Eq. (2).

$$K = K_{IC} = XY\sigma\sqrt{\pi a} \tag{2}$$

where, K_{IC} is the critical stress intensity factor, X is the factor designating type of crack, X = 1 for simple interior crack, X= 1.12 for simple surface crack, Y is the geometry factor, σ is applied or design stress, and a is the crack length.

Where, Y is a geometric factor, reflecting the shape of crack and geometry of sample, σ is the stress applied, a represents crack length [24]. The applied stress or design stress can be calculated by using Eq. (3).

$$\sigma = \frac{P}{tw} \tag{3}$$

where P represents applied load, t represents the thickness of the specimen and w represents the width of the specimen.

In the case of cyclic loading, the stress intensity factor is modified to account for the maximum and minimum stresses. The range of SIF ΔK, calculated using Eq. (4).

$$\Delta K = K_{max} - K_{min} = Y\sigma\sqrt{\pi a} \tag{4}$$

where ΔK represents the change in stress intensity factor for a crack length of "a". K_{max} and K_{min} represent the maximum and minimum values of LEFMF factor. da/dN ratio represents the change in crack length with respect to the change in number cycle of loading and it designates the crack propagation rate. N represents the cycle of loading.

In modelling related work, the variation of the ratio da/dN is plotted against the change in stress intensity factor (ΔK). The basic curve is divided into three parts. Part 1 belongs to a minimum value of ΔK. In this part, no crack propagation is possible when the intensity factor value is less than the minimum one. In Part 2 of the curve, a governing Paris law Eq. (5) holds good between ΔK and da/dN. Part 3 belongs to a behaviour of the alloy where accelerated fatigue crack growth is noticed under cyclic loading conditions [25]. The authors in [26] also utilised the Paris Law relationship and estimation to identify the crack propagation in a detailed way. The following Paris law as shown in Fig. 4 holds good for the part 2 of the plot drawn between ΔK and da/dN.

$$\frac{d_a}{\mathrm{dN}} = C\,\Delta K^m \tag{5}$$

where C and m are material constants and that are calculated empirically [28].

Another model evaluating the crack propagation in aluminium alloys under corrosion fatigue reveals that the crack growth experiences a hysteresis effect. Moreover, the pre-corrosion characteristics of the specimen before the test significantly influence the test results. Due to all the influencing factors, the relationship between the ratio of da/dN and ΔK is evolved as follows Eq. (6) [29,30].

$$\mathrm{Log}\left(\frac{d_a}{\mathrm{dN}}\right) = \log C + \mathrm{m}\log(\Delta K') \tag{6}$$

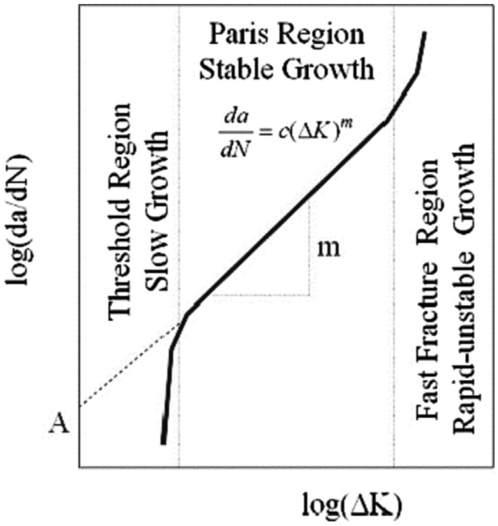

Fig. 4. Overview of Paris Law Crack Growth Regimes [27].

where $\Delta K'$ represents the change in intensity factor after the corrosion test.

The theoretical work related to crack initiation and propagation requires to be studied into two parts. Part one is concerned with modelling crack nucleation under the influence of factors like pit depth, pit density, and variable humidity conditions. The second part discussed the modelling of crack growth in the metallic alloys needs to incorporate the parameters like hydrogen environment, grain boundary effects, crack length and temperature etc., into the governing equation of cracking deformation behaviour of the model to be developed. The theoretical model considering the aforementioned parameters shall give an accurate correlation between experimental data and theoretical formulation.

In a study, the crack growth rate variation with the crack length for different groups of specimens at various periods of corrosion experiments. One of the related graphs, Fig. 5 shows the effect of corrosion experimentation for 192 h on the crack growth variation with respect to crack length. In addition, it revealed that the

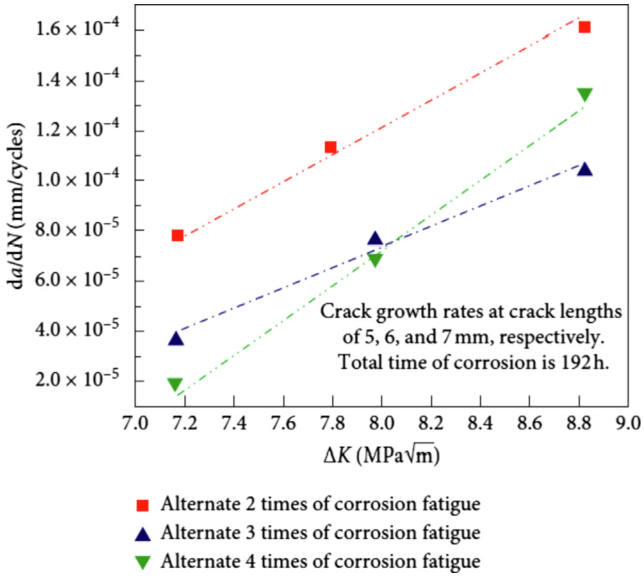

Fig. 5. The crack growth rate variation with crack length for different groups of specimens [20].

increase in time of the corrosion experiment enhances the crack growth rate.

The modelling of stress induced corrosion failures in metallic alloys are using various proposed mechanisms namely slip dissolution, surface mobility theory and oxidation model etc. [31]. Based on film rupture mechanism, oxide scale formation, scale rupture and reformation of the passive layer are considered. Crack tip strain rate, charge oxidation density and stress intensity factors are governing the developed model with the following mathematical expression depicted in Eq. (7). The crack tip growth rate is directly proportional charge density and molecular weight of the materials.

$$V_{ct} = \frac{M}{z\rho F}\frac{Q_f}{\varepsilon_f}\left(\frac{d\varepsilon}{dt}\right) \tag{7}$$

where V_{ct} -Crack tip growth rate, M – Molecular weight of the material, z – Charge of anodic dissolved material, ρ – Density of corroding species, F – Faraday Constant, Q_f – Charge Density per film rupture event, ε_f- Oxide fracture strain, $\frac{d\varepsilon}{dt}$ – Crack tip strain rate.

2.4. Effect of loading system on crack propagation

The fatigue crack rates of the metallic alloys depends on the materials and the loading ratio or stress ratio (R) of the applied cyclic loading. The Fig. 6 shows the effect of R -ratios on the stress intensity factor and fatigue crack rates. It is witnessed that loading ratio has significant effect on the stress intensity factor range ΔK and crack growth rate da/dN under various values of R-ratio. The R -ratio is a crucial because, when in service, many engineering structures are subjected to varied amplitude loads, which has a substantial impact on the crack propagation rate. The stress intensity factor range has been used as the driving force in a straightforward calculation that takes the R -ratio into account. Several materials' fatigue crack propagation rates from literature were studied using the Paris law equation. These revised data are clustered in a small area around the $R = 0$ fracture growth rate curve.

2.5. Effect of temperature and relative humidity on fatigue crack propagation

The above Fig. 7 shows the fatigue crack propagation (FCP) vs temperature of magnesium AZ61 material. The magnesium AZ61 alloy used to study the FCP behaviour at various temperature such as room temperature (RT), 60 °C and 120 °C. The test results reveals that, FCP rate increase in temperature in AZ61. The da/dN verses K curve curved, which corresponded to a fracture transition from a mixed intergranular and trans-granular fracture this is because of the growth of grain size at 120 °C.The study also includes the effect of relative humidity on FCP of magnesium AZ61 alloy. The 45% and 100% relative humidity (RH) used for the study shown in Fig. 8. The test results inferred that, the increase in RH values, significantly improved the FCP. The primary reason for increasing in FCPs in wet air is the hydrogen embrittlement and secondary phase particles in microstructure facilitated FCP crack initiation [33].

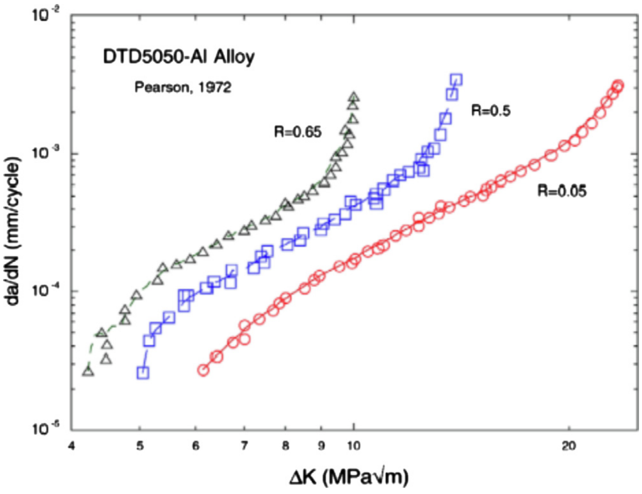

Fig. 6. Crack growth rate curve under different loading ratios (R) [32].

2.6. Measuring techniques used for crack propagation analysis

Measuring techniques used for crack propagation analysis are as follows:

- Digital Image Correlation (DIC)
- High-Speed Camera Image Sequence Processing
- Silicon-Rubber Replica Method

2.6.1. Digital Image correlation (DIC)

As seen in Fig. 8, a stereo DIC system was utilised to quantify the 3D displacement of the test sample. Due in large part to its simplicity of use and high resolution of the generated measurements, digital image correlation (DIC) has developed into a potent full-field strain mapping measurement tool. Full-field results and scalability are two very exciting new tools that DIC adds to the experimentalist's toolbox. In particular, this scalability is starting to pay off in nano- and micro-scale research fields. The full-field measurement of the strain, as opposed to single point measurements at a gauge location, is of course DIC's biggest benefit over conventional strain gauge methods. The advantage is seen in experiments like these, where the strain field continuously changes during the experiment as the fracture tip grows. It should be noted that DIC's strain resolution falls short of a strain gauge when applied correctly. Resolution for strain gauges is normally 1–10, whereas it is typically a few hundred for DIC. The fact that DIC does not experience the vibration problems that the other widely used full-field method, electronic speckle pattern interferometry (ESPI) does is a significant advantage. This decreased resolution is not a concern for many experiments, including the determination of the failure of these aluminium specimens, and is balanced by the benefits of DIC [34].

2.6.2. High-speed camera image sequence processing

The ability to analyze the whole surface of a sample at once makes it possible to simultaneously observe several cracks, which is a clear benefit of high-speed, camera-based techniques for identifying cracks and calculating their crack propagation velocity. Processing interactive image sequences is tedious, though. As a result, automated methods are necessary for the effective processing of experimental data. Reliable and accurate image processing procedures should also eliminate observer mistakes to improve findings reproducibility. Although using a high-speed camera requires a significant amount of instrumental work, it has the clear benefit of allowing for non-contact, spatiotemporally resolved data as opposed to single-point measurements [35].

2.6.3. Silicon-rubber replica method

The silicon rubber replica is one of the methods used to measure the crack propagation in metals which are subjected to cyclic loading. The replication process generally entails creating exact reproductions of a desired region using a variety of rapid drying/curing or imprint materials. The benefit of this technique is that it preserves the surface for further inspection once the precise loca-

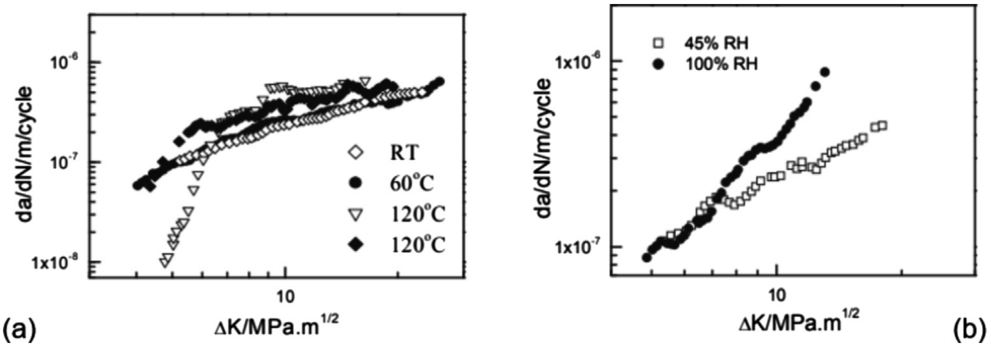

Fig. 7. (a) FCP rate vs temperature of AZ61 (b) FCP rate vs relative humidity of AZ61 [33].

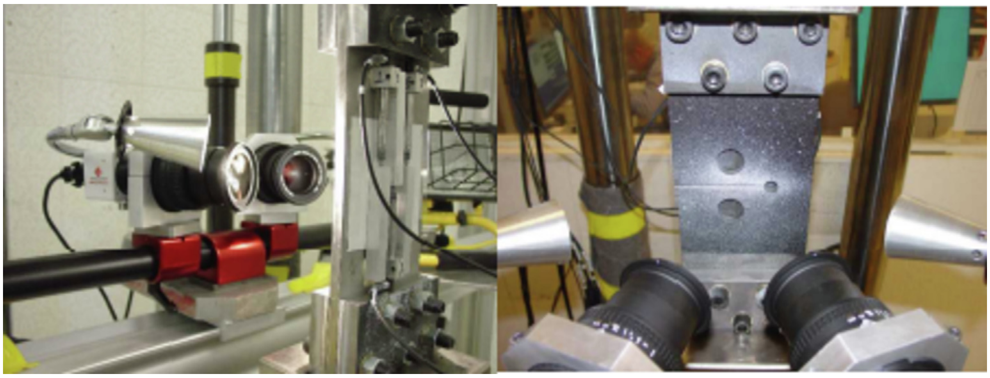

Fig. 8. Stereo DIC camera arrangement and sample on the MTS test frame [34].

tion of the major crack is established. This method could detect the cracks less than 25 µm with a resolution of 0.1 µm and its highly accurate when compared to destructive analysis. The experiments take less time to complete since the replicas are applied in a simpler way than other replica technologies (such as acetyl cellulose film) [36].

3. Conclusions

The corrosion assisted cracking of various metallic materials are reviewed and it is understood that the crack initiation happens due to the corrosion phenomena called pitting. Further, the crack growth takes place with the aid of loading system and environmental conditions. In this regard, the couple load such as temperature and humidity can play a significant role in making the crack growth behaviour faster. Both stress corrosion cracking and fatigue load assisted cracking can be influenced by the combined effect of the environment and the loading systems. The various parameters involved in the crack propagation can be utilized to develop a model governing the corrosion assisted cracking of the metallic alloys. The study also reveals that, under different values of the loading ratio (R-ratio), it is concluded that the loading ratio significantly affects the stress intensity factor range ΔK and the crack growth rate da/dN. Because many engineering structures are subjected to varying amplitude loads while they are in operation, which has a significant impact on the fracture propagation rate. The different measurement of crack propagation rate are measured accurately recorded using the techniques like Digital Image Correlation (DIC), High-Speed Camera Image Sequence Processing and Silicone-Rubber replica methods.

CRediT authorship contribution statement

Ibrahim M. Alqahtani: Methodology. **Andrew Starr:** Supervision. **Muhammad Khan:** Supervision.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Y. Enomoto, Steam turbine retrofitting for the life extension of power plants, in: Advances in Steam Turbines for Modern Power Plants, Woodhead Publishing, 2017, pp. 397–436, ISBN 9780081003145. https://doi.org/10.1016/B978-0-08-100314-5.00017-8.

[2] Y. Katz, N. Tymiak, W.W. Gerberich, Evaluation of Environmentally Assisted Crack Growth, Mechanical Testing and Evaluation, in: Howard Kuhn, Dana Medlin (Eds.), ASM Handbook, vol. 8, ASM International, 2000, pp. 612–648. https://doi.org/10.31399/asm.hb.v08.a0003309.

[3] A. Hojná, Environmentally Assisted Cracking Initiation in High-Temperature Water, Metals 11 (2021) 199, https://doi.org/10.3390/met11020199.

[4] Z.D. Harris, J.T. Burns, The Effect of Loading Rate on the Environment-Assisted Cracking Behaviour of AA7075-T651 in Aqueous NaCl Solution, Corros. Mater. Degrad. 2 (2021) 360–375, https://doi.org/10.3390/cmd2030019.

[5] K. Zhao, S. Wang, H. Xue, Z. Wang, Effect of Material Heterogeneity on Environmentally Assisted Cracking Growth Rate of Alloy 600 for Safe-End Welded Joints, Materials (Basel). 14 (20) (2021) 6186, https://doi.org/10.3390/ma14206186.

[6] J. Yang, Micromechanical analysis of in-plane constraint effect on local fracture behaviour of cracks in the weakest locations of dissimilar metal welded joint, Acta Metall. Sin. 30 (2017) 840–850, https://doi.org/10.1007/s40195-017-0599-y.

[7] N. Brown, P. Kramer, F. Friedersdorf, M. Schindelholz, J. Siegel, Environmentally assisted cracking measurements in structural aluminum alloys under accelerated test conditions, Corrosion 72 (11) (2016) 1351–1362, https://doi.org/10.5006/2085.

[8] Alireza Khalifeh, Stress Corrosion Cracking Damages, 2019. https://doi.org/10.5772/intechopen.80826.

[9] J.R. Donahue, A.B. Lass, J.T. Burns, The interaction of corrosion fatigue and stress-corrosion cracking in a precipitation-hardened martensitic stainless steel, npj Mater. Degrad. 1 (2017) 1, https://doi.org/10.1038/s41529-017-0013-2.

[10] S. Shipilov, Mechanisms for Corrosion Fatigue Crack Propagation, Fatigue Fract. Eng. Mater. Struct. 25 (2002) 243–259, https://doi.org/10.1046/j.1460-2695.2002.00447.x.

[11] H. Uchida, S. Hanaki, M. Nakatani, Y. Tanaka, K. Itakura, T. Takahashi, Tsutomu Murai, A study on stress corrosion cracking of magnesium alloys by slow strain rate technique, in: 18th International Corrosion Congress 2011, vol. 2, 2011, pp. 1383–1389.

[12] D. Little, B. Connolly, J. Scully, An electrochemical framework to explain the intergranular stress corrosion behaviour in two Al–Cu–Mg–Ag alloys as a function of aging, Corros. Sci. 49 (2007) 347–372, https://doi.org/10.1016/j.corsci.2006.04.024.

[13] J. Martin, Aluminum-Lithium Alloys, Annu. Rev. Mater. Sci. 18 (2003) 101–119, https://doi.org/10.1146/annurev.ms.18.080188.000533.

[14] R. Braun, Environmentally assisted cracking of aluminium alloys, Materialwiss. Werkstofftech. 38 (9) (2007) 674–689, https://doi.org/10.1002/mawe.200700204.

[15] I.M. Robertson, P. Sofronis, A. Nagao, M.L. Martin, S. Wang, D.W. Gross, K.E. Nygren, Hydrogen Embrittlement Understood, Metall. Mater. Trans. A 46 (6) (2015) 2323–2341, https://doi.org/10.1007/s11661-015-2836-1.

[16] Y. Lee, R.P. Gangloff, Measurement and Modeling of Hydrogen Environment-Assisted Cracking of Ultra-High-Strength Steel, Metall. Mater. Trans. A 38 (13) (2007) 2174–2190, https://doi.org/10.1007/s11661-006-9051-z.

[17] A.R. Troiano, The Role of Hydrogen and Other Interstitials in the Mechanical Behaviour of Metals, Metallogr. Microstruct. Anal. 5 (2016) 557–569, https://doi.org/10.1007/s13632-016-0319-4.

[18] Unai De Francisco, Nicolas O. Larrosa, Matthew J. Peel, Hydrogen environmentally assisted cracking during static loading of AA7075 and AA7449, Mater. Sci. Eng.: A 772 (2020), https://doi.org/10.1016/j.msea.2019.138662, ISSN 0921-5093.

[19] X. Zhao, G.S. Frankel, Effects of Relative Humidity, Temper, and Stress on Exfoliation Corrosion Kinetics of AA7178, CORROSION 62 (11) (2006) 956–966, https://doi.org/10.5006/1.3278234.

[20] B. Maier, G.S. Frankel, Pitting Corrosion of Silica-Coated Type 304 Stainless Steel Under Thin Electrolyte Layers, CORROSION 67 (3) (2011) 035004-1–035004-10.

[21] ASTM G67–99, Standard Test Method for Determining the Susceptibility to Intergranular Corrosion of 5XXX Series Aluminum Alloys by Mass Loss After Exposure to Nitric Acid (NAMLT Test), ASTM International, West Conshohocken, PA, 1999.

[22] R. Wang, A fracture model of corrosion fatigue crack propagation of aluminum alloys based on the material elements fracture ahead of a crack tip, Int. J. Fatigue 30 (8) (2008) 1376–1386, https://doi.org/10.1016/j.ijfatigue.2007.10.007.

[23] M. Fonte, S. Stanzl-Tschegg, B. Holper, E. Tschegg, V. Asuri, The microstructure and environment influence on fatigue crack growth in 7049 aluminum alloy at different load ratios, Int. J. Fatigue 23 (2001) 311–317, https://doi.org/10.1016/S0142-1123(01)00179-7.

[24] T.L. Anderson, Fracture Mechanics: Fundamentals and Application, CRC Press, Boston, 1991.

[25] A. Mehmanparast, F. Brennan, I. Tavares, Fatigue crack growth rates for offshore wind monopile weldments in air and seawater: SLIC inter-laboratory test results, Mater. Des. 114 (2017) 494–504.

[26] F. He, V.K. Thakur, M. Khan, Evolution and new horizons in modeling crack mechanics of 3D printing polymeric structures, Mater. Today Chem. 20 (2021) 100393, https://doi.org/10.1016/j.mtchem.2020.100393.

[27] N. Pugno, M. Ciavarella, P. Cornetti, A. Carpinteri, A generalized Paris' law for fatigue crack growth, J. Mech. Phys. Solids 54 (7) (2006) 1333–1349.

[28] P.C. Paris, F. Erdogan, A critical analysis of crack propagation laws, J. Basic Eng. 85 (1960) 528–534.

[29] T. Zhang, Y. He, C. Li, T. Zhang, S. Zhang, Effect of Alternate Corrosion and Fatigue on Fatigue Crack Growth Characterization of 2024-T4 Aluminum Alloy, Math. Probl. Eng. 2020 (2020) 1–15.

[30] Na Zhao, Yan-qing Yang, Ming Han, Xian Luo, Guang-hai Feng, Rong-jun Zhang, Finite element analysis of pressure on 2024 aluminum alloy created during restricting expansion-deformation heat-treatment, Trans. Nonferr. Metals Soc. China 22 (9) (2012) 2226–2232, https://doi.org/10.1016/S1003-6326(11)61453-2, ISSN 1003-6326.

[31] Bernadett Spisák, Szabolcs Szávai, Mechanisms of Stress Corrosion Cracking, 2019. https://doi.org/10.26649/musci.2019.052.

[32] X. Huang, T. Moan, Improved modelling of the effect of R-ratio on crack growth rate, Int. J. Fatigue 29 (2007) 591–602.

[33] R.C. Zeng, E.H. Han, W. Ke, Effect of Temperature and Relative Humidity on Fatigue Crack Propagation Behavior of AZ61 Magnesium Alloy, Mater. Sci. Forums 546-549 (2007) 409–412.

[34] P. Cheng, M.A. Sutton, H.W. Schreier, S.R. McNeill, Full-field speckle pattern image correlation with B-spline deformation function, Exp. Mech. 42 (3) (2002) 344–352.

[35] Frank Liebold, Ali A. Heravi, Oliver Mosig, Manfred Curbach, Viktor Mechtcherine Hans-Gerd Maas, Crack Propagation Velocity Determination by High-speed Camera Image Sequence Processing, Materials 13 (2020) 4415, https://doi.org/10.3390/ma13194415.

[36] J.B. Jordon, J.D. Bernard, J.C. Newman, Quantifying microstructurally small fatigue crack growth in an aluminum alloy using a silicon-rubber replica method, Int. J. Fatigue 36 (1) (2012) 206–210.

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Alqahtani, Ibrahim

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