



# Environment-Assisted Fatigue Crack Propagation (EAFCP) Behavior of Ti64 Alloy Fabricated by Direct Energy Deposition (DED) Process

HOJUN OH, JUNG GI KIM, JUNMIN LEE, and SANGSHIK KIM

Environment-assisted fatigue crack propagation (EAFCP) behavior of as-built and  $\beta$ -annealed Ti64 specimens manufactured by direct energy deposition (DED) process was examined in air and 3.5 pct NaCl solution under an anodic applied potential of  $E_{\text{corr}} + 0.05 V_{\text{SCE}}$ . As-built DED Ti64 specimen was found to be susceptible to EAFCP in 3.5 pct NaCl solution, and  $\beta$  anneal did not decrease the sensitivity to EAFCP. It was suggested that  $\text{Cl}^-$  bearing environment tended to decrease the tendency for crack bifurcation during EAFCP of DED Ti64 specimen, because of local corrosion damage at boundaries between  $\alpha$  and  $\beta$  phases. Since crack bifurcation increases the resistance to fatigue crack propagation (FCP) by reducing effective  $\Delta K$  (stress intensity factor range) at the tip of crack, the FCP rates of DED Ti64 specimen increased in 3.5 pct NaCl solution.

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## 1. INTRODUCTION

CORROSION-RESISTANT and damage-tolerant Ti-6Al-4V (Ti64) alloy is a workhorse alloy of Ti industry, and is widely applied for corrosion and fracture critical parts in biomedical and aerospace industries.<sup>11–20</sup> Recently, additive manufacturing (AM) technique is widely utilized for manufacturing a variety of Ti64 products.<sup>16,21–23</sup> A large number of studies have been conducted to identify the relationship between processing parameters, microstructure and mechanical properties of AM Ti64 products.<sup>16–19</sup> The microstructure of Ti64 alloy consists of interphaxial  $\beta$  phase and  $\alpha$  phase, either equiaxed or acicular. It has been well established that the FCP resistance of AM Ti64 specimen was inferior to that of conventionally manufactured counterpart, due to fine microstructural features associated with AM process. The FCP behavior of AM Ti64 specimen could therefore be improved with annealing, particularly above  $\beta$  transus temperature, due to the coarsening of acicular  $\alpha$  platelets.<sup>17,21</sup> Regardless of manufacturing processes, Ti64 alloy has an excellent

electrochemical stability in corrosive environment, which can however be influenced by microstructural characteristics.<sup>17,22–25</sup> Yang *et al.* have reported that corrosion resistance of arc-deposited Ti64 specimen with the microstructure of acicular  $\alpha$  platelets in NaCl solution was comparable to that of ingot metallurgy processed Ti64 alloy having bimodal structure of equiaxed  $\alpha$  and acicular  $\alpha$  phases.<sup>17,21</sup> They also showed that corrosion resistance of Ti64 specimen manufactured by different AM techniques (*i.e.*, arc-deposition and selective laser melting) varied, arguing that type, size and morphology of constituent phases could affect the corrosion behavior of AM Ti64 specimen.<sup>17,21</sup> Seo *et al.* reported that electrochemical stability of AM Ti64 specimen was similar to that of conventionally manufactured Ti64 alloy in 3.5 pct NaCl solution.<sup>17,21</sup> Dai *et al.* proposed that heat treatment at 500, 850 and 1000 °C, respectively, for 2 h tended to decrease the corrosion resistance of AM Ti64 specimen by selective laser melting technique in 3.5 pct NaCl solution by deteriorating the stability of passive film.<sup>17,21</sup>

It has been well established that Ti64 alloy has excellent resistance to both fracture and corrosion. However, it can be susceptible to environment-assisted fracture (EAF) in  $\text{Cl}^-$  bearing environment,<sup>116,171</sup> because  $\text{Cl}^-$  can attack passive film on the surface.<sup>115,171–200</sup> The EAF phenomena include, for example, stress corrosion cracking (SCC) and environment-assisted fatigue crack propagation (EAFCP). While a large number of literature are available on the EAF behavior of Ti64 alloys, the studies on AM Ti64 products are relatively limited.<sup>171,201</sup> Jesus *et al.* have reported approximately 3.3 times greater fatigue crack

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## **Table of Contents Environment Assisted Fatigue**

1. Understanding the eBook Environment Assisted Fatigue
  - The Rise of Digital Reading Environment Assisted Fatigue
  - Advantages of eBooks Over Traditional Books
2. Identifying Environment Assisted Fatigue
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Environment Assisted Fatigue
  - User-Friendly Interface

4. Exploring eBook Recommendations from Environment Assisted Fatigue
  - Personalized Recommendations
  - Environment Assisted Fatigue User Reviews and Ratings
  - Environment Assisted Fatigue and Bestseller Lists
5. Accessing Environment Assisted Fatigue Free and Paid eBooks
  - Environment Assisted Fatigue Public Domain eBooks
  - Environment Assisted Fatigue eBook Subscription Services
  - Environment Assisted Fatigue Budget-Friendly Options
6. Navigating Environment Assisted Fatigue eBook Formats
  - ePub, PDF, MOBI, and More
  - Environment Assisted Fatigue Compatibility with Devices
  - Environment Assisted Fatigue Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Environment Assisted Fatigue
  - Highlighting and Note-Taking Environment Assisted Fatigue
  - Interactive Elements Environment Assisted Fatigue
8. Staying Engaged with Environment Assisted Fatigue
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Environment Assisted Fatigue
9. Balancing eBooks and Physical Books Environment Assisted Fatigue
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Environment Assisted Fatigue
10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine Environment Assisted Fatigue
  - Setting Reading Goals Environment Assisted Fatigue
  - Carving Out Dedicated Reading Time

12. Sourcing Reliable Information of Environment Assisted Fatigue
  - Fact-Checking eBook Content of Environment Assisted Fatigue
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
  - Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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