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Extreme Value Statistics Analysis of Process Defects in Additive Manufacturing Materials

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Extreme Value Statistics Analysis of Process Defects in Additive Manufacturing Materials

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1. INTRODUCTION

- **Fatigue strength** is the threshold (or non-propagation) condition of **short cracks** present in all materials which leads to **defects when exceeded.**
- When these **defects/detrimental microstructure features are rare**, standard methods used in calculating threshold conditions become inappropriate[1].
- **Extreme Value Statistics** (EVS) are the appropriate tools used in **estimating these maximum inclusions** that causes the defect when **fatigue strength is exceeded**[2].
- The intuition behind this is that in presence of inclusions at a given stress level, the material will fail if the *largest particle* exceeds the limit size for the *threshold condition* (at that stress level), because **fatigue strength depends on defects size.**
- This then implies that the ***fatigue quality*** of any material **cannot depend on the average of inclusions or pore/cavities but on the extreme values of such.**
- EVS become a perfect tool to deploy[3] because the fatigue properties of additive manufacturing materials are controlled by process-induced defects[4].

2. Extreme Value Statistics for Defect Analysis

Regardless of the parent distribution, the ***distribution of the largest inclusion*** can be asymptotically estimated[5] by:

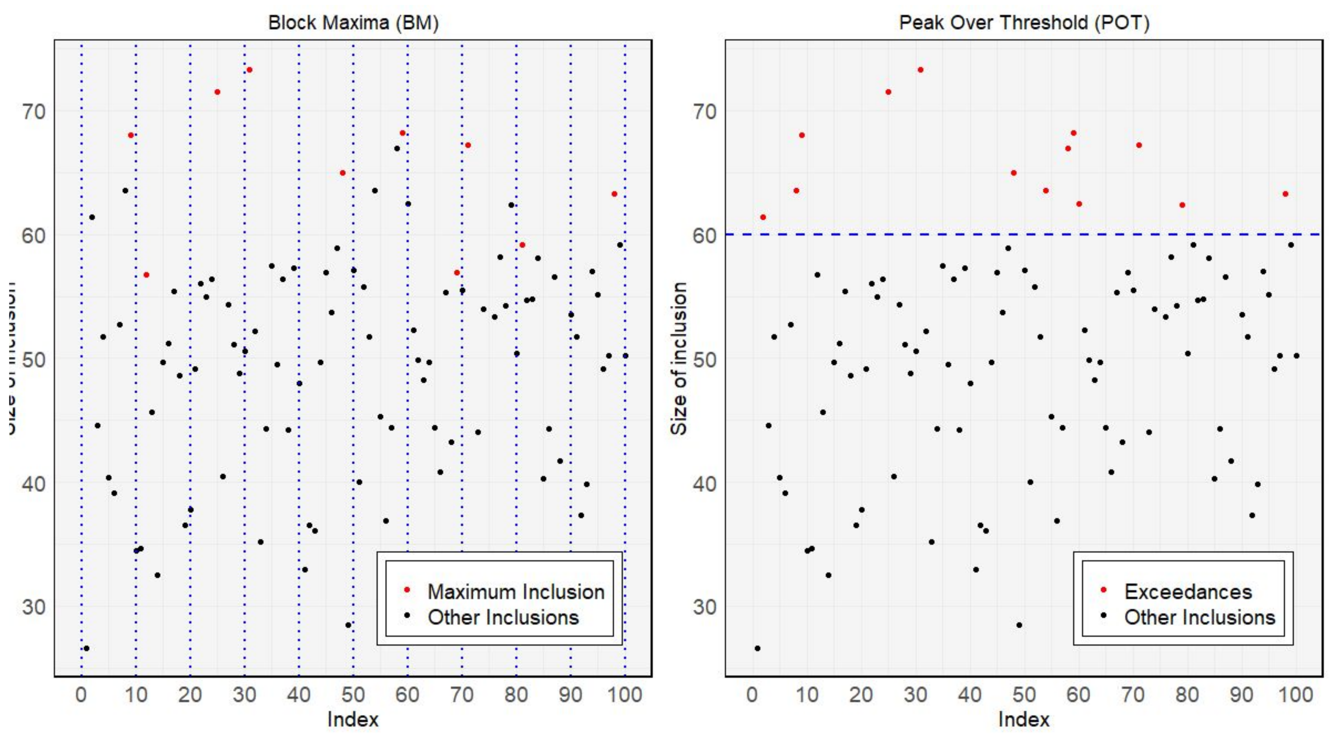
1. *Block Maximum (BM)* Approach

Generalized Extreme Value (GEV) Distribution

- Weibull distribution when shape parameter is less than 0
- Frechet distribution when shape parameter is greater than 0
- Gumbel distribution when shape parameter is approaches 0

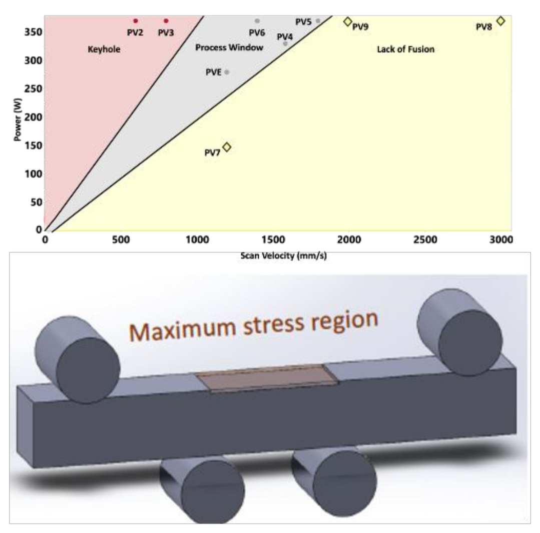
2. *Peak Over Threshold (POT)* Approach

Generalized Pareto (GPD) Distribution



3. SOURCE OF DATASET

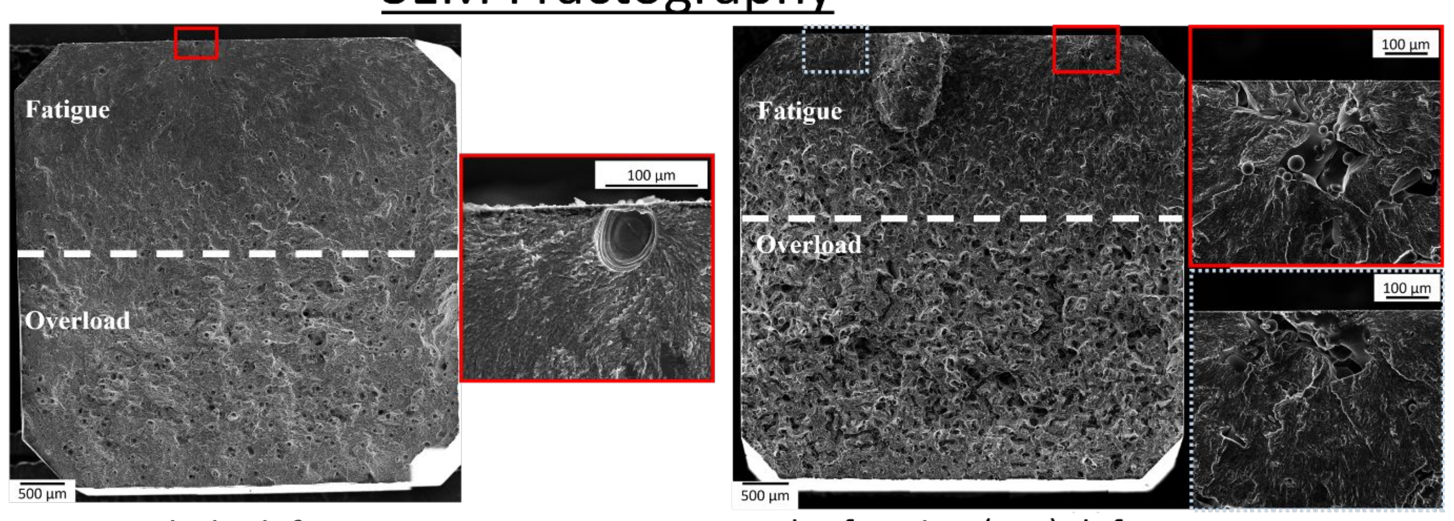
AM process parameter exploration correlating defect morphology with fatigue (*S-N*) in **Ti-6Al-4V**[6]



Four-point bend (4PB) fatigue

Fatigue fracture

SEM Fractography



Keyhole defects

Lack-of-Fusion (LoF) defects

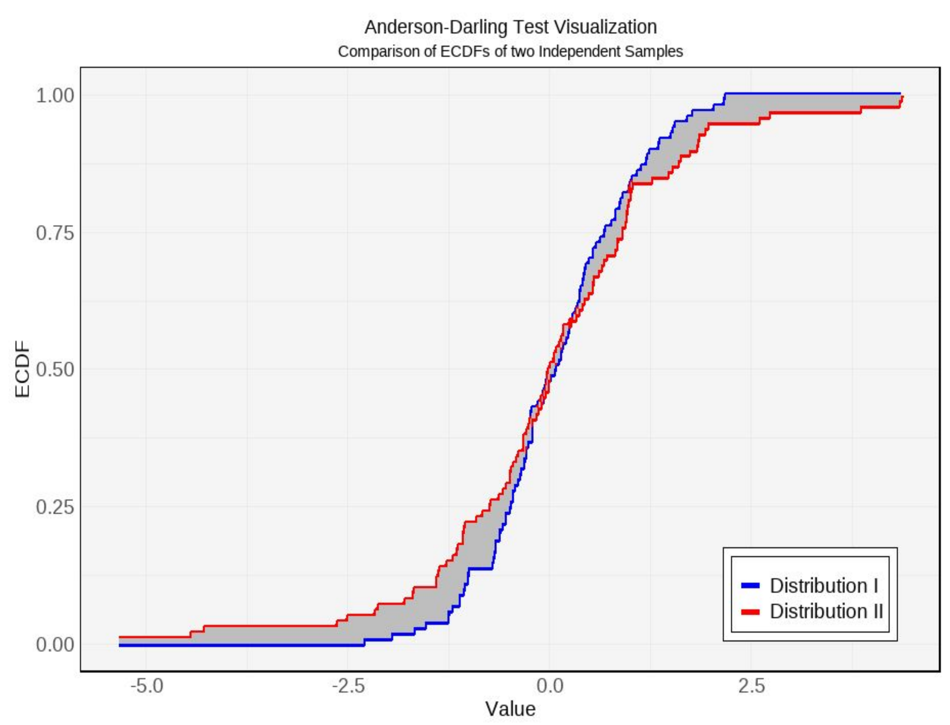
4. METHODOLOGY

Anderson-Darling (AD) Test

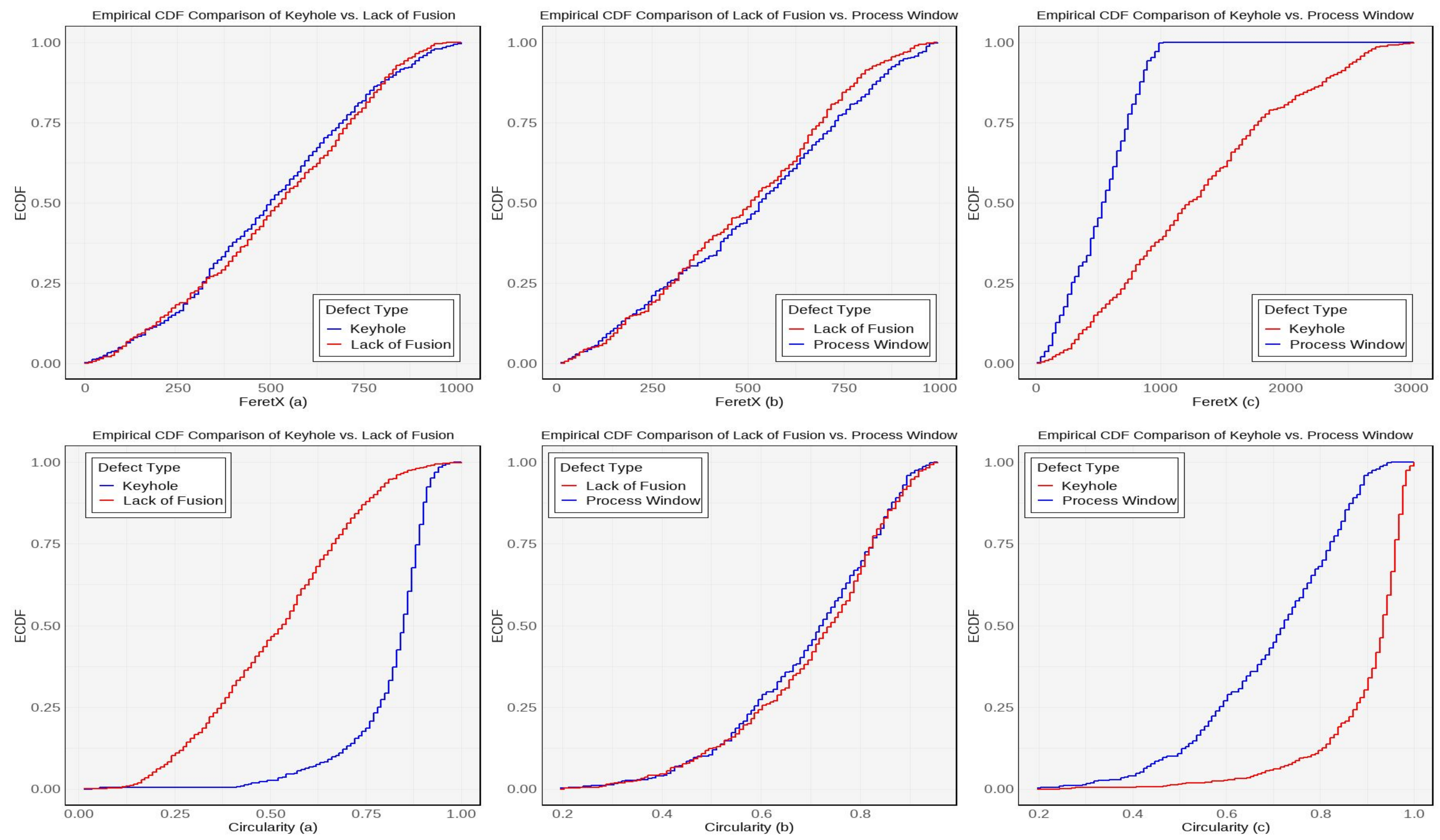
- AD is a goodness-of-fit test that handles the tail of the distributions well by adding weights to each distance through the predicted variance of the combined sample's **Empirical Cumulative Distribution Function (ECDF)** at each point[7].
- We adopted the AD test since we are interested in EVS.
- Based on **13 features of interest**, we use the AD test to determine if defects from different defect regions, such as **keyhole, LoF, and process window,** have the same distribution or otherwise.

Akaike Information Criterion (AIC)/Bayesian Information Criterion (BIC)

- After the AD test, we used AIC/BIC to determine the exact distribution that each of the 13 features follows.



5. RESULTS



Distribution of defects based on AIC/BIC values across 3 specimens[7]

- **Lack of Fusion (Specimen I):-** GPD: FeretX, Area, Y coordinates, and Feret angle. Inconclusive: X coordinate (AIC and BIC values disagree). GEV: remaining features.
- **Keyhole (Specimen II):-** GPD: FeretY, Area, X coordinates, Y coordinates,and Feret angle. Inconclusive: FeretX. GEV: remaining features.
- **Process Window (Specimen III):-** GEV: Perimeter, Circularity, Roundness, and Solidity. Inconclusive: Feret length and Aspect Ratio. GPD: remaining features.

6. CONCLUSIONS

Determination of the distribution of features in different defect regions

- Through AD test statistics, we determined if features from different defect regions follow the same distribution or otherwise and then plotted the ECDF for visualization.
- We then use AIC/BIC to determine the distribution of these features of interest.

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8. ACKNOWLEDGEMENT

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