Model-Based Prognosis for Remaining Useful Life Prediction of Composite Components

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Research Objective

In order to predict the **remaining useful life (RUL) of composite structures**, especially, we focused on the fatigue damage analysis of lower control arm (LCA) as component under severe load conditions.

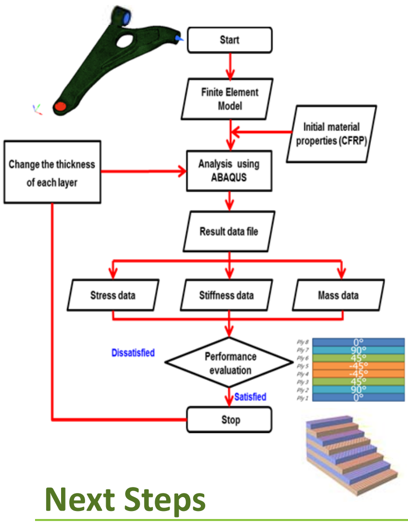
Particle filter method is employed **to estimate model parameters characterizing the cumulative damage evolution** according to the cycles of fatigue analysis

Expected Contributions

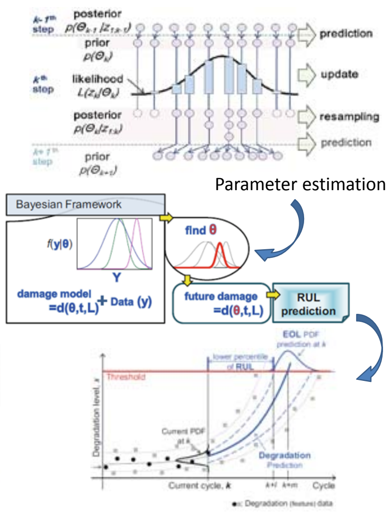
- By estimating the remaining useful life (RUL) and verifying its durability of composite materials, we can expect to reduce of carbon emission from the long-term perspective by expanding its applicability
- By applying CFRP material to LCA parts, we achieved a weight reduction about 25% compared to conventional aluminum materials

State of Research

Optimization Progress



RUL Prediction (Particle Filter)



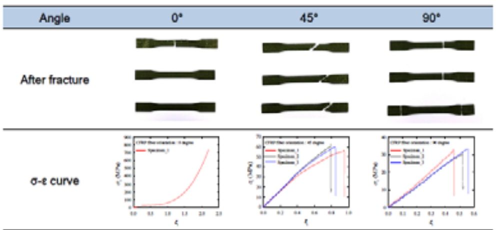
Next Steps

- It is expected that more reliable and advanced technology can be obtained by measuring the cumulative damage amount through the actual durability test in the LCA component unit to verify the simulation result

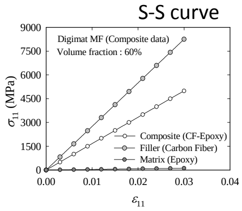
Research Details

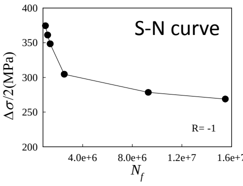
Material Properties

- Laminated CFRP [0/90/45/-45]s



S-S curve





Fatigue Damage Evolution

- Continuum Damage Mechanics

$$N_f = \frac{1}{1-\alpha}\left(\frac{\sigma_{max}-\bar{\sigma}}{C(\bar{\sigma})}\right)^{-\beta} = \frac{\sigma_u-\sigma_{max}}{\left\langle \sigma_{max}-\sigma_l(\bar{\sigma})\right\rangle}\frac{1}{aC_0^{-\beta}}\left(\frac{\sigma_{max}-\bar{\sigma}}{1-b\bar{\sigma}}\right)^{-\beta}$$

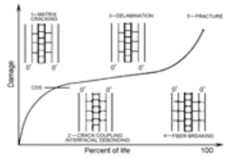
$$D = \left(\frac{N}{N_f}\right)^{1/(1-\alpha)}$$

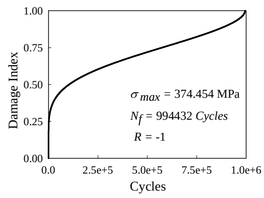
$\bar{\sigma}$: non-null mean stress
C_0, β, α: Wohler and damage model
α: load function

▶ Integration of the damage law: $D_i^{1-\alpha_i} = D_{i-1}^{1-\alpha_i} + \frac{N_i}{N_{fi}}$

▶ Damage model: $D = q\times\left(\frac{N}{N_f}\right)^m + (1-q)\times\left(\frac{N}{N_f}\right)^c$

Damage evolution curves are nonlinear with the number of cycles

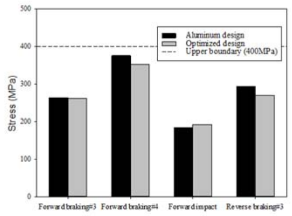


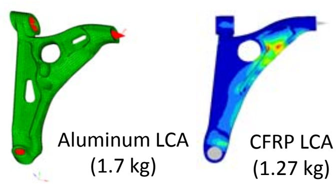


Cumulative damage curve

Design Optimization for CFRP LCA

Max. principal stress of inertia relief analysis with Aluminum- and optimized-design

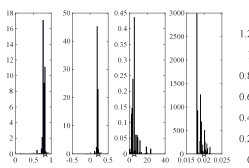




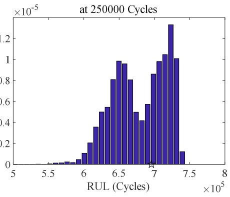
- Optimization of laminated thickness

The number of ply	Degree(°)	Thickness (mm)
Ply1/Ply8	0	2.088
Ply2/Ply7	90	1.798
Ply3/Ply6	45	2.064
Ply4/Ply5	-45	4.049
Total Thickness (mm)		20

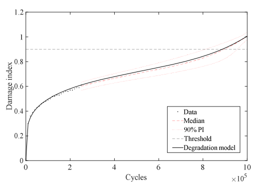
RUL Prediction Result



Distribution of estimated parameter



Result of predicted RUL



Damage prediction

Method	Damage model	5 % (Cycles)	50 % (median) (Cycles)	95 % (Cycles)	Current Cycles	Threshold
PF	562,513	452,935	573,072	692,780	250,000	0.85
	636,850	596,426	648,398	719,951	250,000	0.90
	695,831	618,438	682,778	731,180	250,000	0.95

Acknowledgments and References

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[Ref 1] Kim, NH, An, D, & Choi, JH (2017). Prognostics and health management of engineering systems. *Switzerland: Springer International Publishing*.
[Ref 2] Lim, J et al., (2016). Sizing Optimization of CFRP Lower Control Arm Considering Strength and Stiffness Conditions. *Journal of CDE*. 21(4), pp.389-396.