Static Response and Failure Prediction of Anisotropic Material Extrusion Polymer Parts


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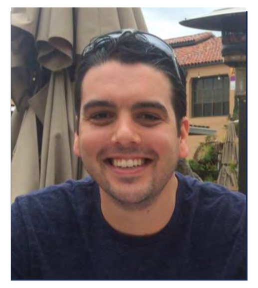
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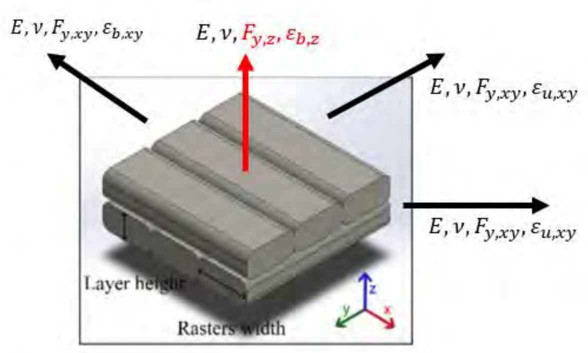
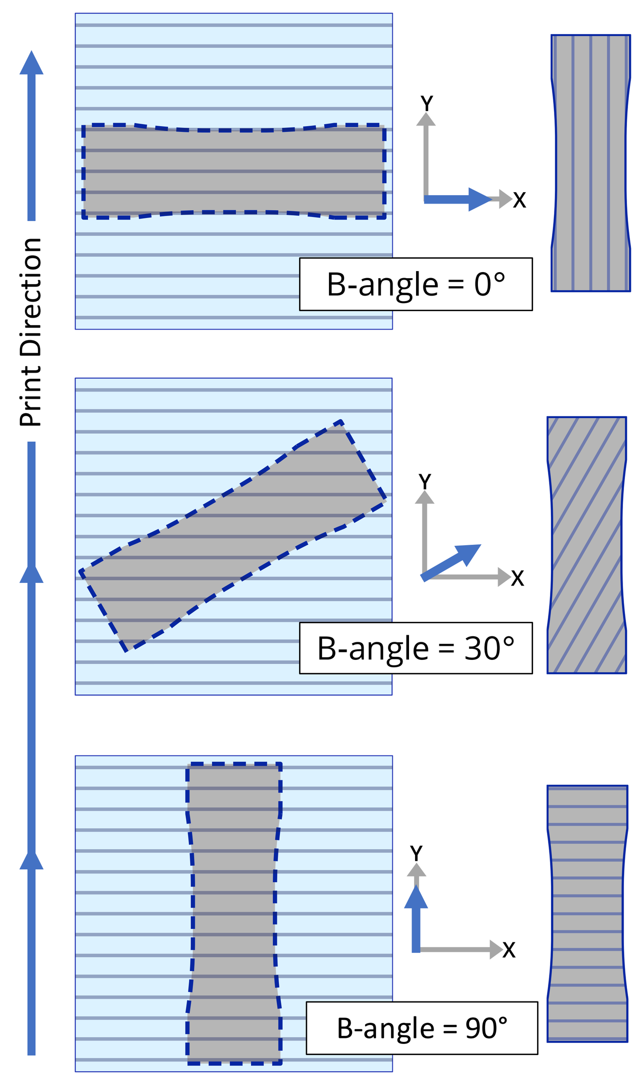
Goals and Scope

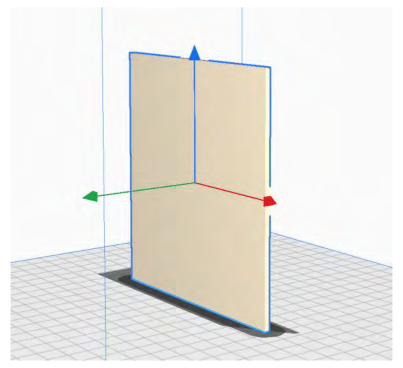
This project works to expand on previous studies regarding of 3D-printed Polyether-ether-ketone (PEEK) element configurations. Assess low-cost 3D printers for low-criticality structures applications and characterize behavior of highly anisotropic layered 3d-printed parts

- Coupons were prepared in B-angle configurations from 0 to 90º.
- Tensile testing of these coupons inform constitutive properties of the material during both elastic behavior and failure.
- Use of wide coupons and observation of full field strain allows for characterization of transversely isotropic responses.
- Modelling the material in FEM will help to extract PEEK properties and predict possible areas and modes of failure.

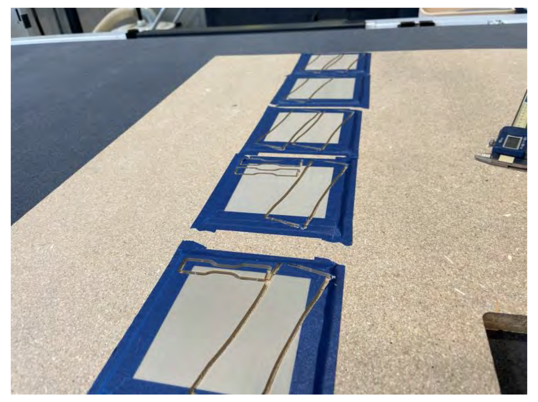




Coupon Preparation Methods



Fifty 116 x 116 mm blanks printed to ensure uniformity in printing across tests and orientations.



Coupons were extracted from the blanks using a digital Zünd cutter in the desired B-angle orientation.

After extraction, end tabs were applied to the coupons to ensure full grip on the tensile testing machine

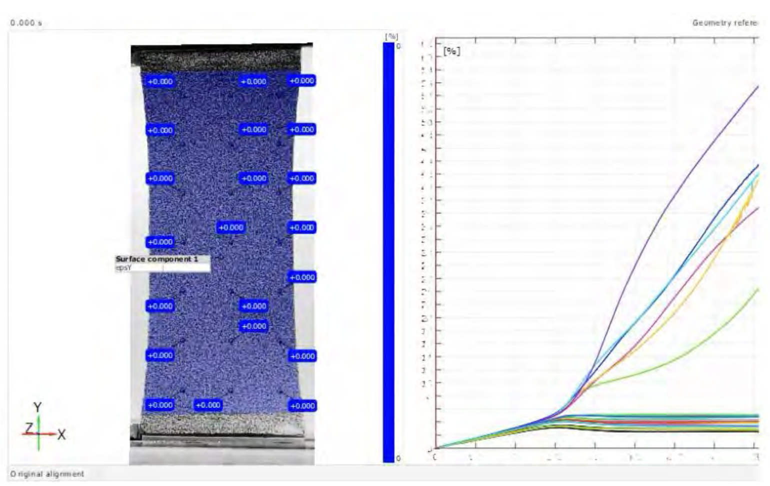
Prior to testing, DIC tattoo paper was applied to the surface of the coupon to enable later analysis of full field strain

Testing

A Shore Western load cell was used to test the wide coupons until failure. Additional flat and vertical traveler testing confirmed consistent production of coupons

Digital Image Correlation & Data Analysis

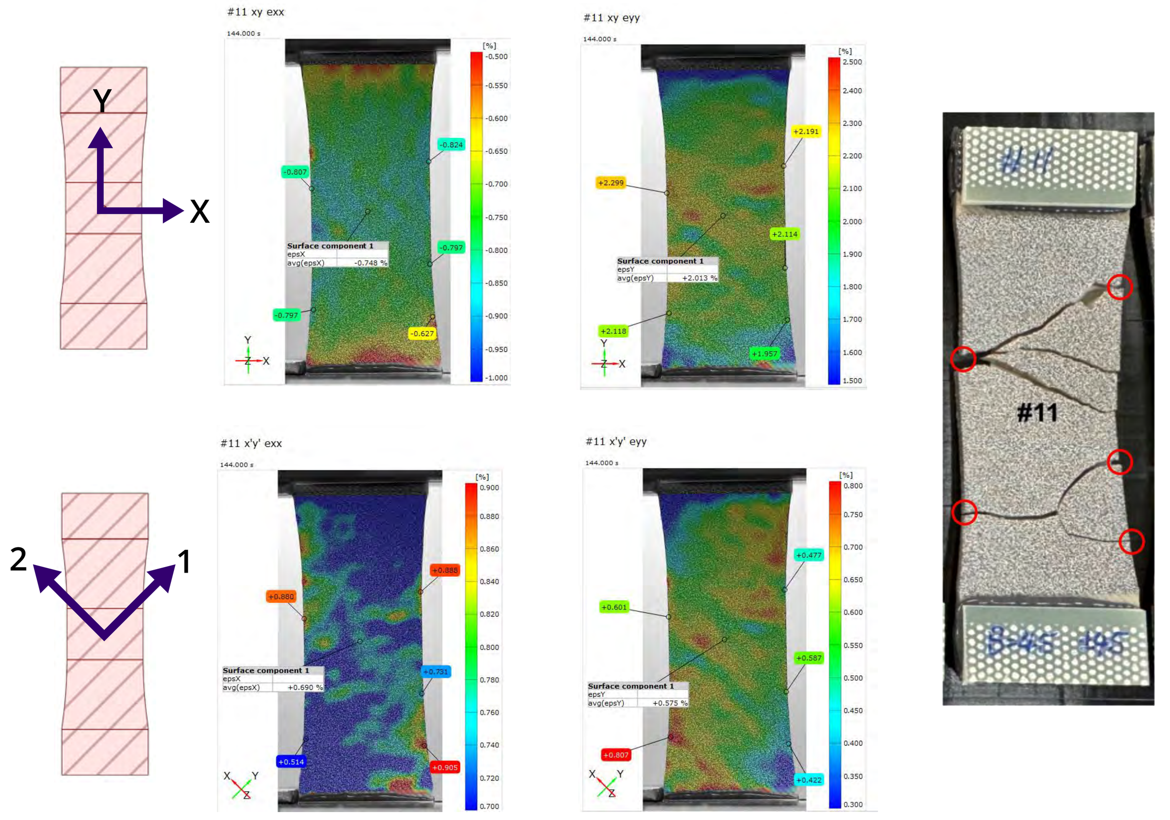
GOM software



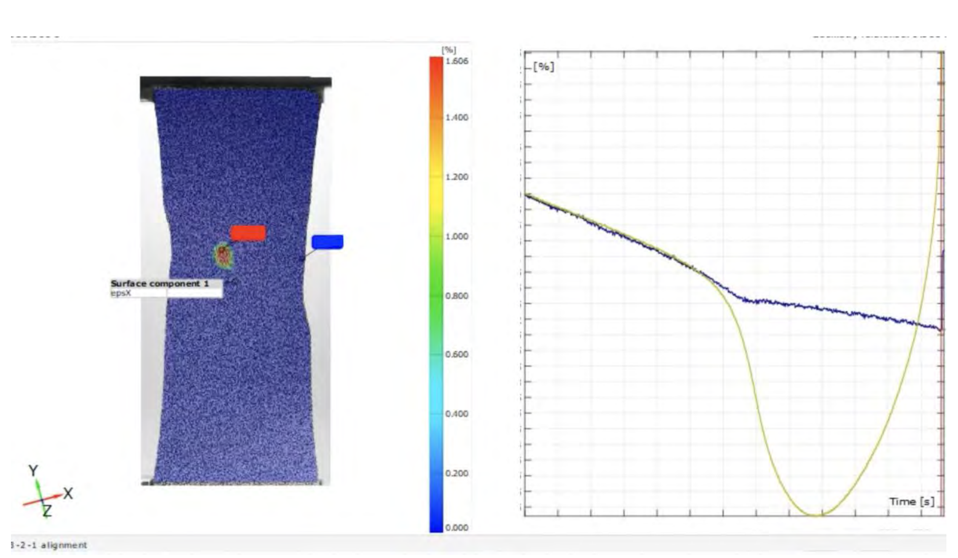
GOM, a digital image correlation software, was used to analyze the full field strain of the coupons. GOM makes it possible to extract normal and shear strains on any given point of the element

Alignment Transformation

Aligning the DIC coordinates with the orientation of the coupon can reveal strain concentrations not seen in the original coordinates- and possible fracture origins.



Hotspot Identification



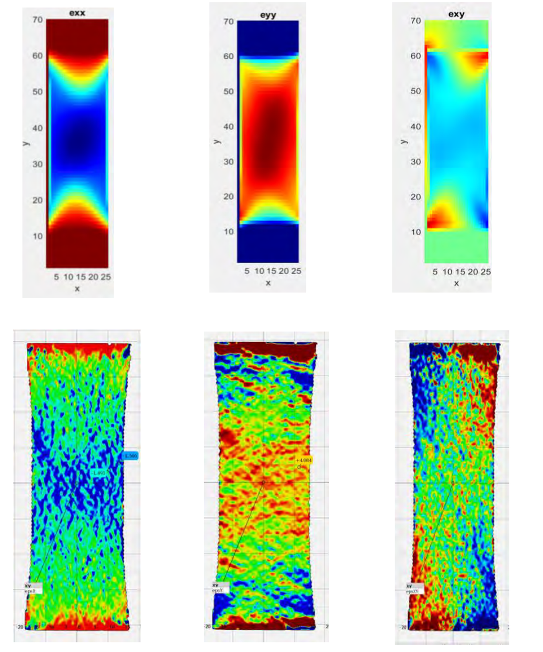
After aligning the coordinates with the raster, the points with the largest growing strain can indicate a point in which the failure line may cross and are particularly evident in plastic behavior.

Modelling

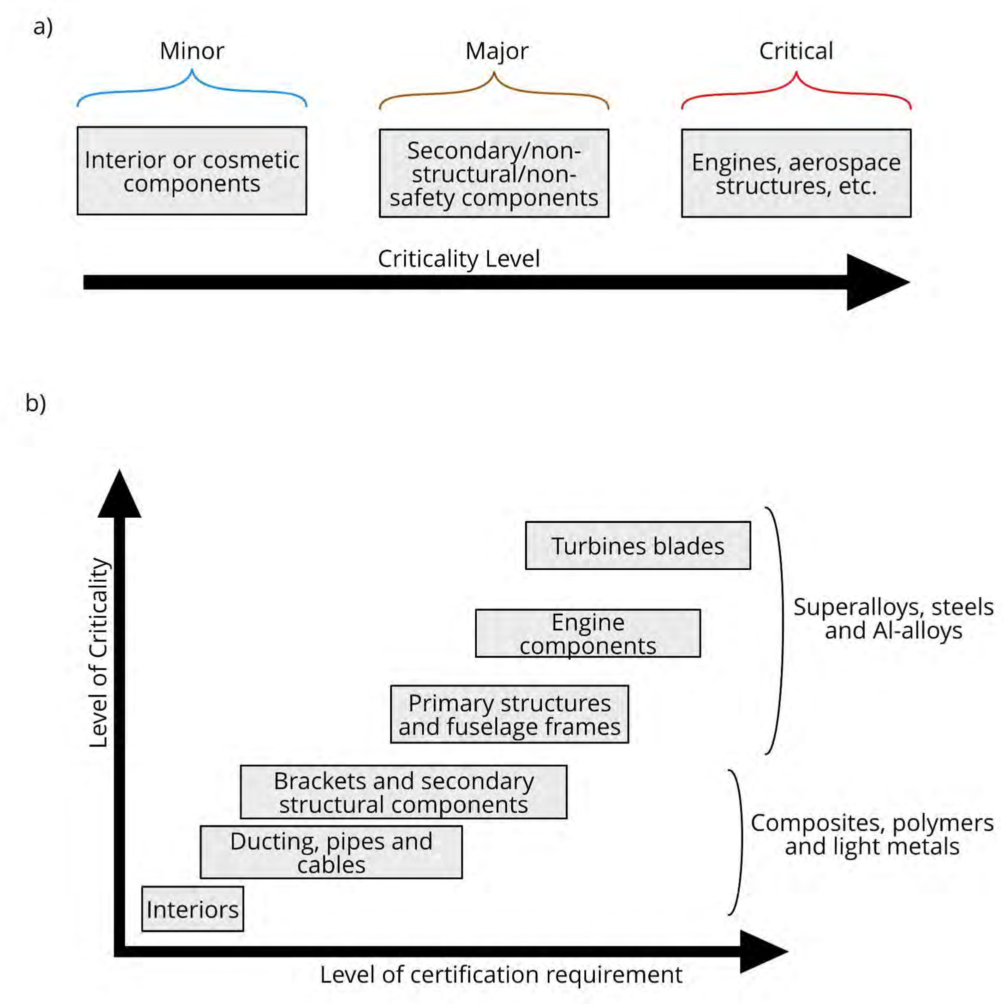
$$\begin{Bmatrix} \epsilon_{11} \\ \epsilon_{22} \\ \epsilon_{33} \\ \epsilon_{12} \\ \epsilon_{13} \\ \epsilon_{23} \end{Bmatrix} = \begin{bmatrix} \frac{1}{E_z} & -\frac{\nu_{zp}}{E_z} & -\frac{\nu_{zp}}{E_z} & 0 & 0 & 0 \\ -\frac{\nu_{zp}}{E_z} & \frac{1}{E_p} & -\frac{\nu_p}{E_p} & 0 & 0 & 0 \\ -\frac{\nu_{zp}}{E_z} & -\frac{\nu_p}{E_p} & \frac{1}{E_p} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{zp}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{zp}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1+\nu_p}{E_p} \end{bmatrix} \begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{12} \\ \sigma_{13} \\ \sigma_{23} \end{Bmatrix}$$

Plane stress and transverse isotropy assumptions allow the preliminary extraction of material properties directly from testing.

Minimization of error in strain between the FEA model and actual coupons will be done by altering material properties. This calibration will lead to predictions for high stress areas- potential failure locations for future tests.



Impact to Boeing



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This project investigates the failure mechanisms and isotropy of 3D printed high-performance polymer, PEEK.

After conducting an extensive study, Boeing will be poised to enhance the critical utilization of 3D-printed polymer in a broader range of aircraft component applications- a sustainable and relatively cost-effective additive manufacturing solution.

1. Singamneni, Sarat & Lv, Yifan & Hewitt, Andrew & Chalk, Rodger & Thomas, Wayne & Jordison, David. (2019). Additive Manufacturing for the Aircraft Industry: A Review. Journal of Aeronautics & Aerospace Engineering. 08. 10.35248/2168-9792.19.8.215.