An Investigation on the Flexural Properties of Fusion Joining of Segmented Wind Turbine Blades

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INTRODUCTION

Recently, wind turbines have been growing larger and larger in an attempt to reduce the levelized cost of energy. However, when wind turbine blades get to a massive scale (150+ meters), it becomes difficult to transport them as a single piece. This has led to the exploration of wind turbine blade segmentation, in which several pieces of a blade are manufactured and transported to be assembled on-site. Our primary focus is investigating the use of carbon fiber laminates or a metal mesh to join these segments.

Several smooth and segmented 3D-printed samples were tested under the three-point bending test to determine their structural integrity and flexural behavior. All samples were tested under the ASTM D790 standard[1]. Three different types of samples were designed in SolidWorks and multiple samples were printed for each type.

MATERIALS AND METHODS

The first sample type that was designed for this experiment (smooth sample) contained a scaled-down version of an airfoil cross-section taken at 75% span from the SNL 100-03 blade[2]. The chord length of this airfoil was 3 inches, and the supporting span length was 12 inches.

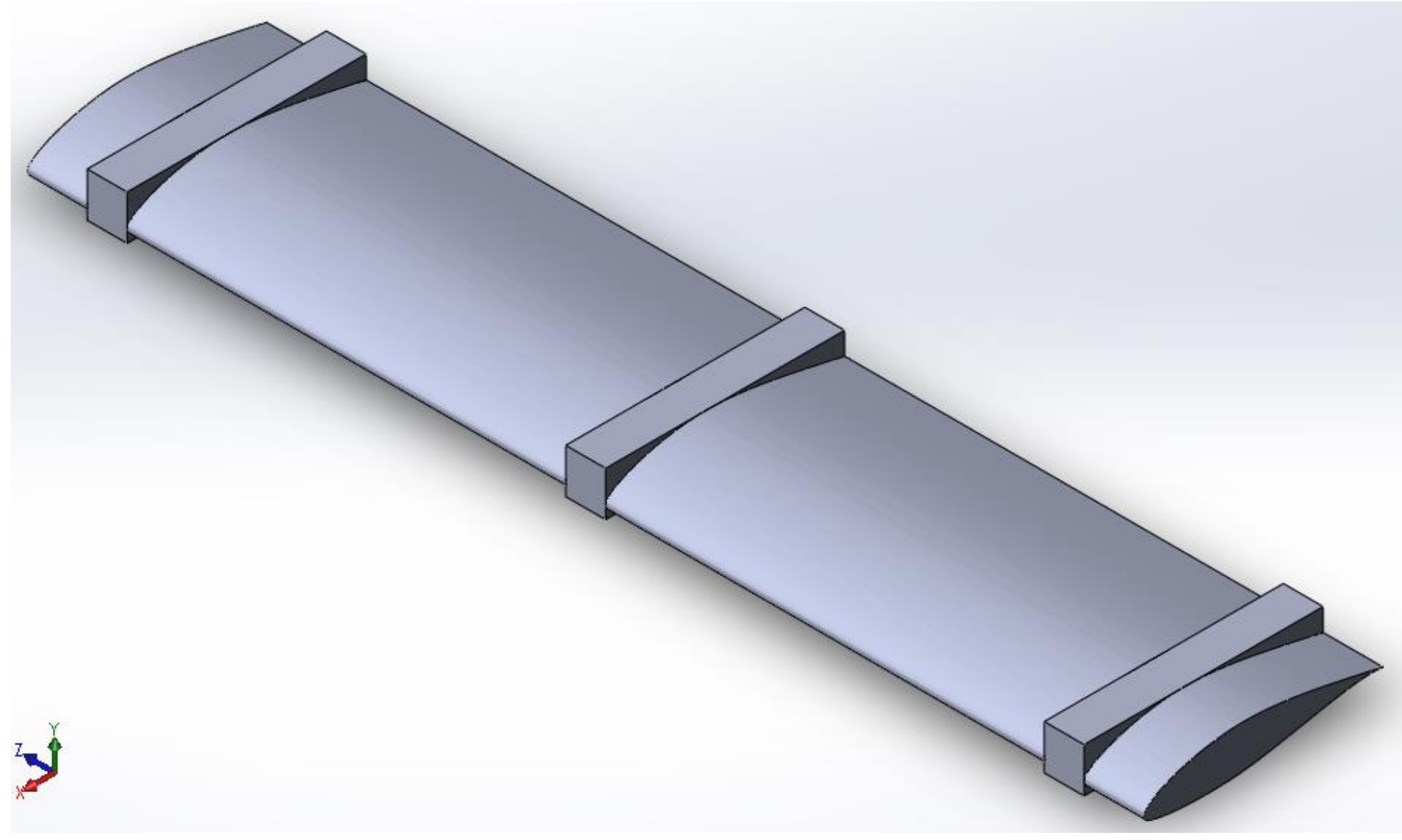

Fig. 1 SolidWorks 3D Model of Smooth Sample Type

The second sample type was identical to the smooth sample but was split exactly at the center of the part (segmented sample). The segmented sample was designed so that the two ends could be joined by resistance welding, where a metal mesh is heated up between the ends until they melt together.

The third and final sample type was designed like the segmented sample but included a mortise and tenon joint (i.e., internal shaft connection) to be able to mate the two parts together with a stronger bonding quality compared to the second sample.

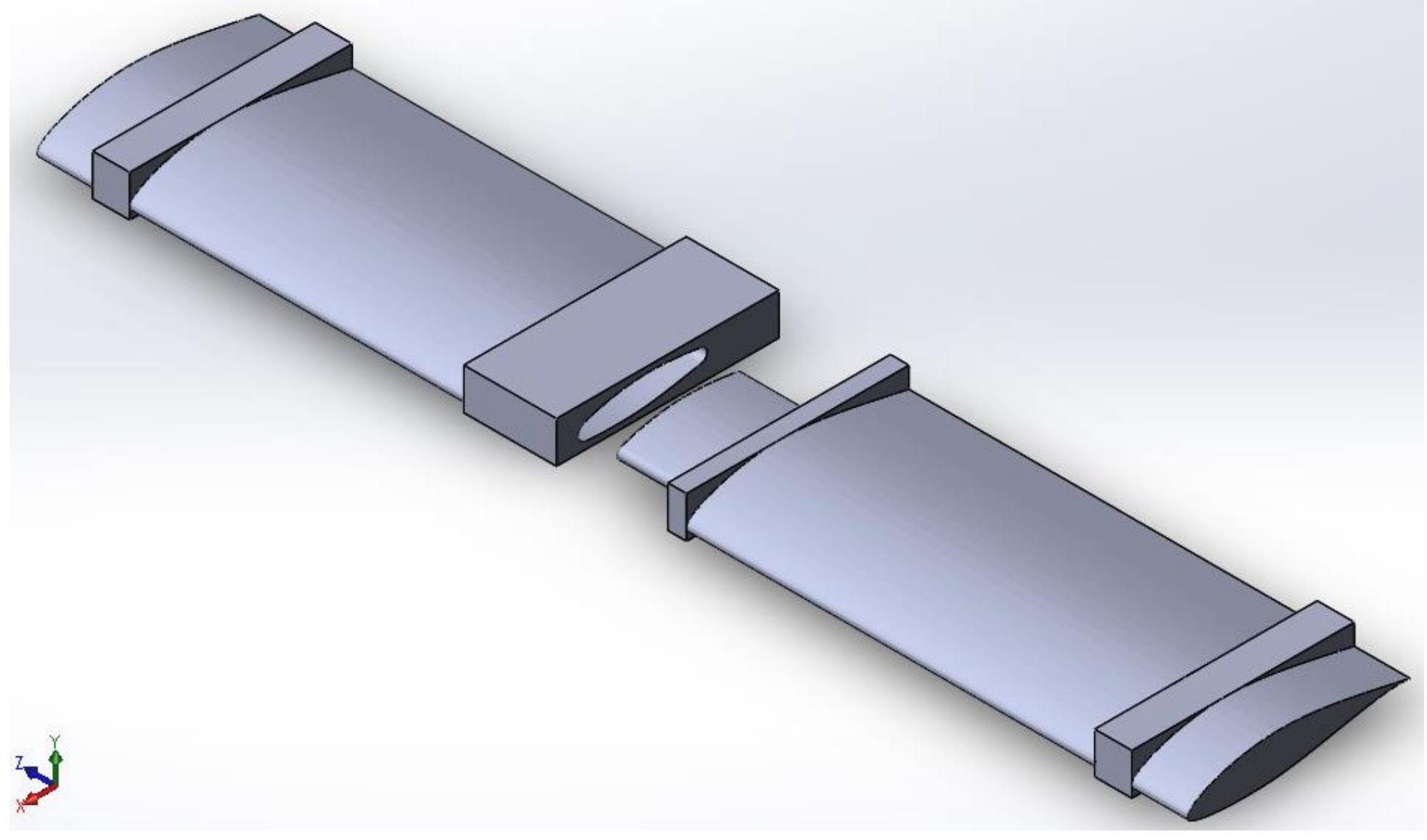

Fig. 2 SolidWorks 3D Model of Segmented with Shaft Sample

RESULTS

The smooth samples were successfully printed and tested. These samples were printed at 40% infill density with a 3D triangular infill pattern using PLA filament. These specimens came out to be 14 inches long, 3 inches wide, and 0.55 inches in height. The applied load and extension of the samples were recorded during the test, and from these parameters, the flexural stress and strain could also be derived.

Table 1 Summary table showing several material characteristics of smooth samples under bending

	Maximum Load (N)	Maximum Extension (mm)	Flexural Strength* (MPa)	Flexural Modulus (MPa)
Sample 1	611.7	33.60	18.34	742.39
Sample 2	540.2	28.87	16.21	711.62
Sample 3	589.5	35.92	17.41	687.00

Unfortunately, the segmented samples were not able to be tested because of issues with misalignment. The resistance welding process was successful but joined the two ends at an offset from each other, potentially affecting the validity of these tests.

* Calculated assuming rectangular geometry of specimen according to ASTM standards

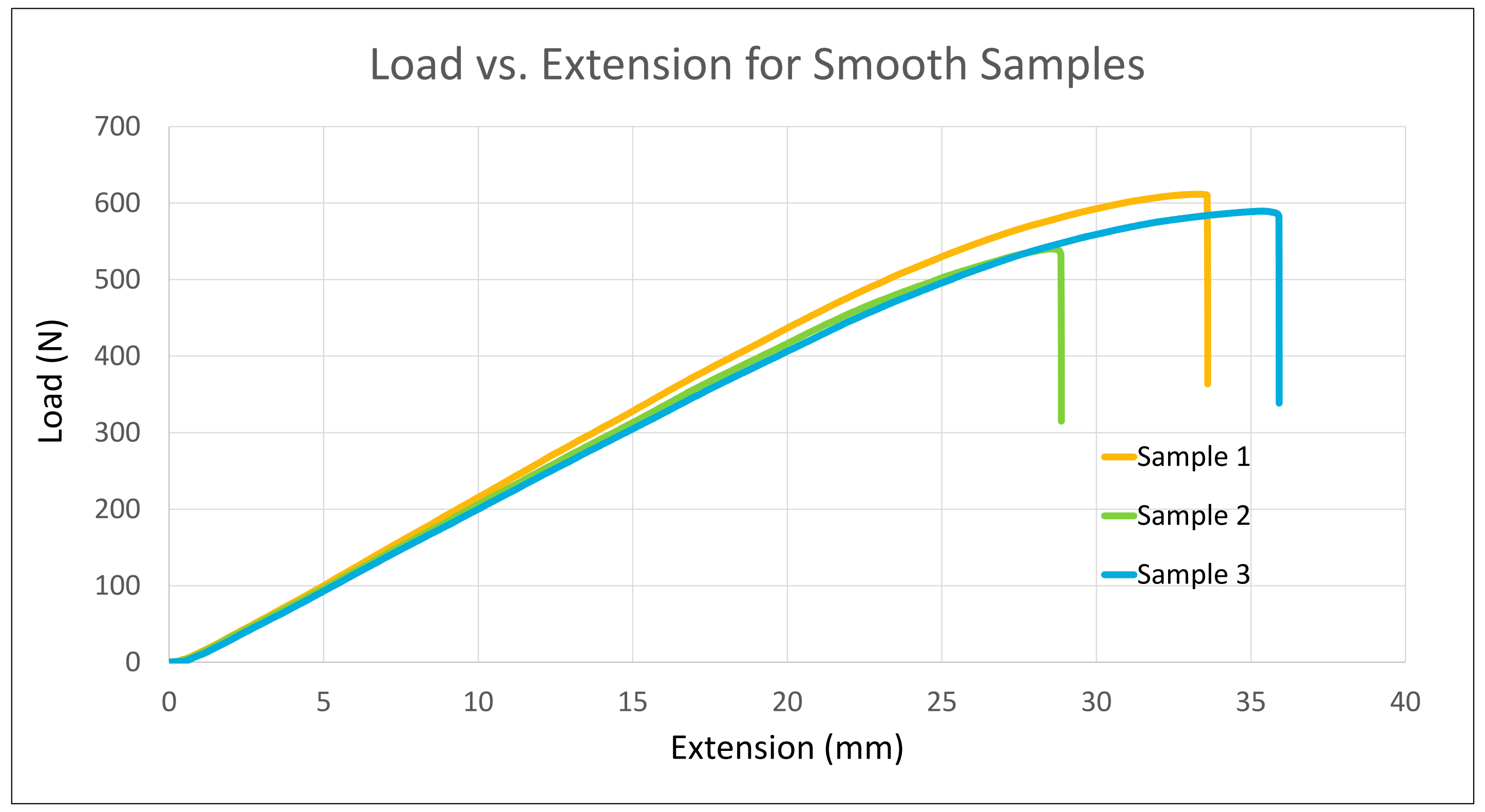

Fig. 6 Load vs. Extension Graph for the three smooth samples tested

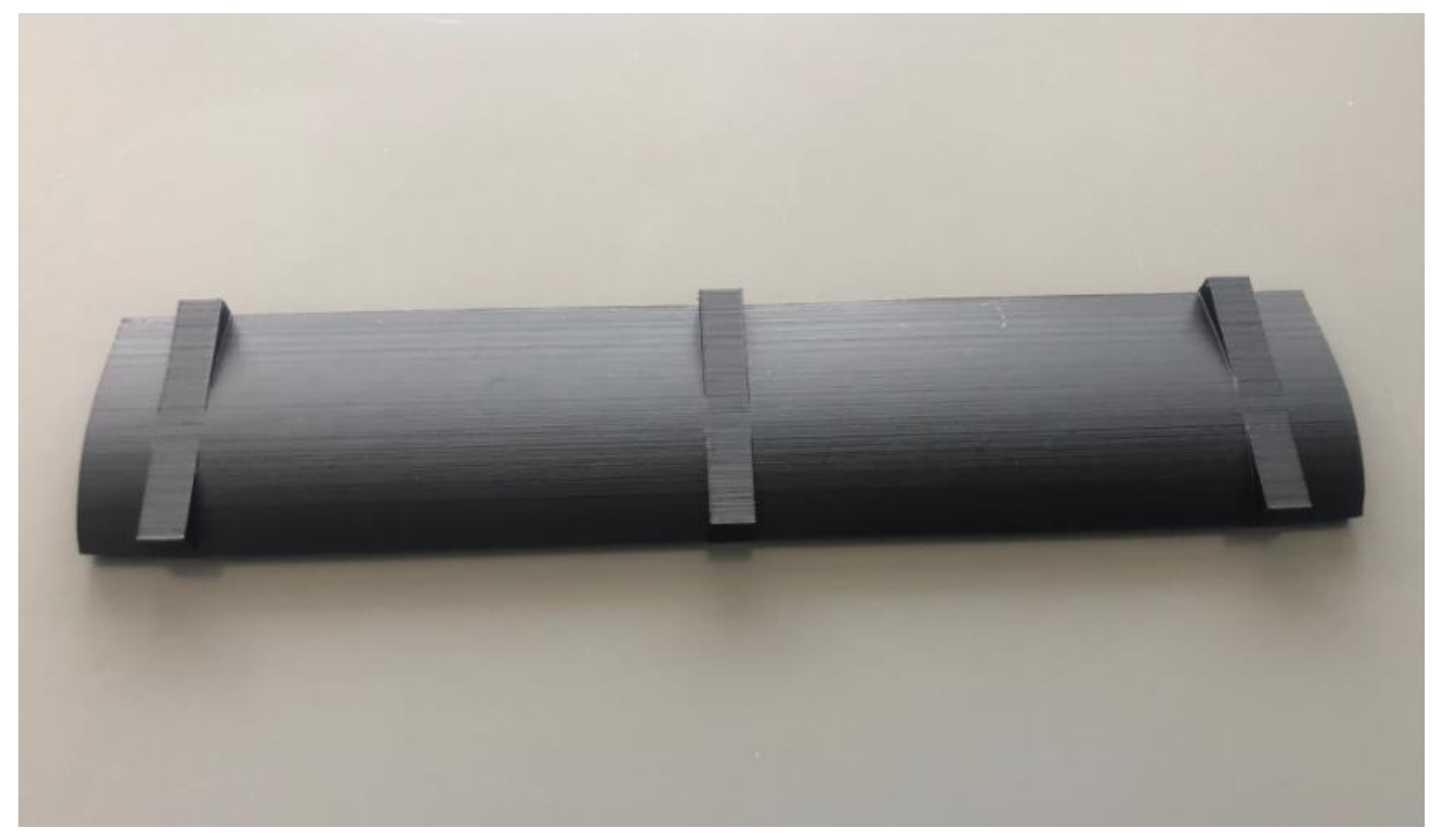

Fig. 3 3D Printed Smooth Sample (Before Testing)
Adapted from Dongyang Cao

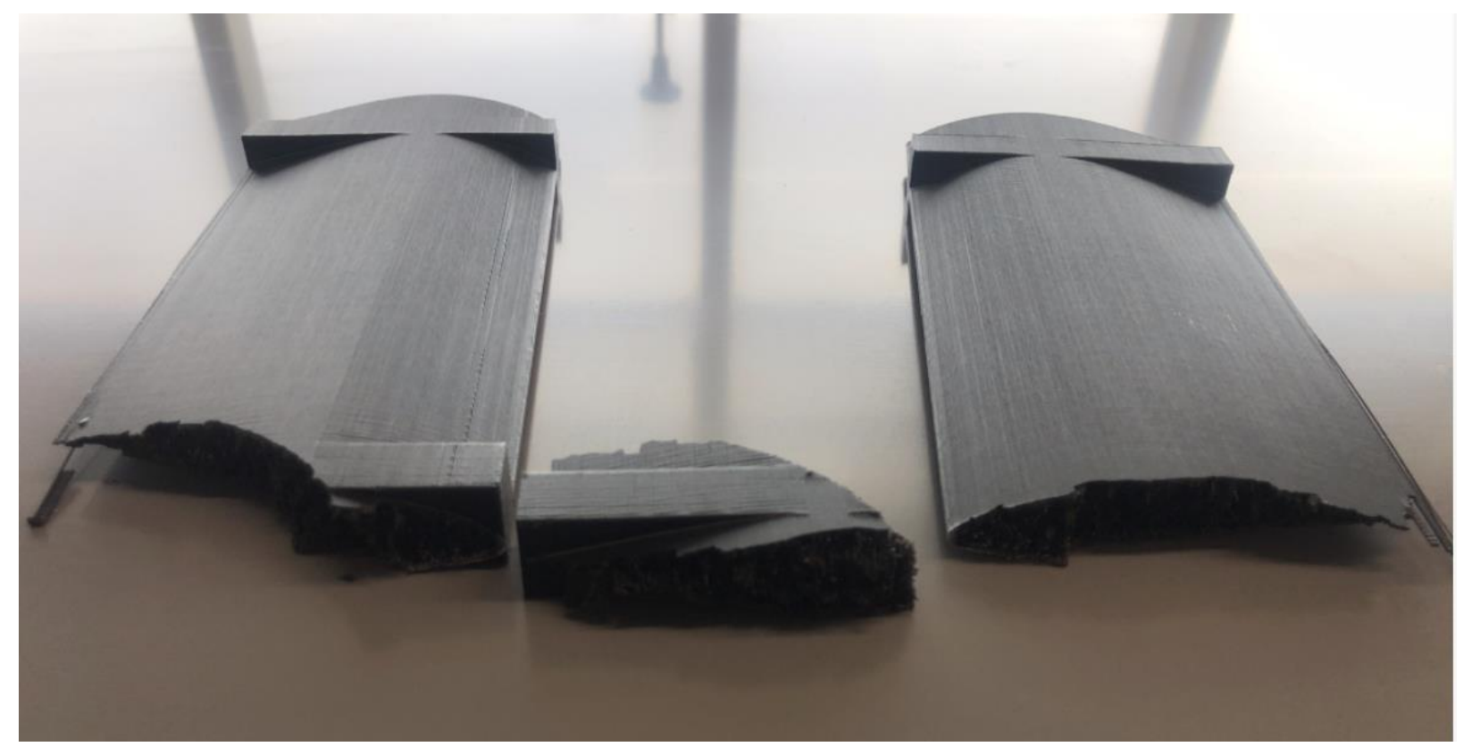

Fig. 4 3D Printed Smooth Sample (After Testing)
(Failure Mode: Catastrophic failure)
Adapted from Dongyang Cao

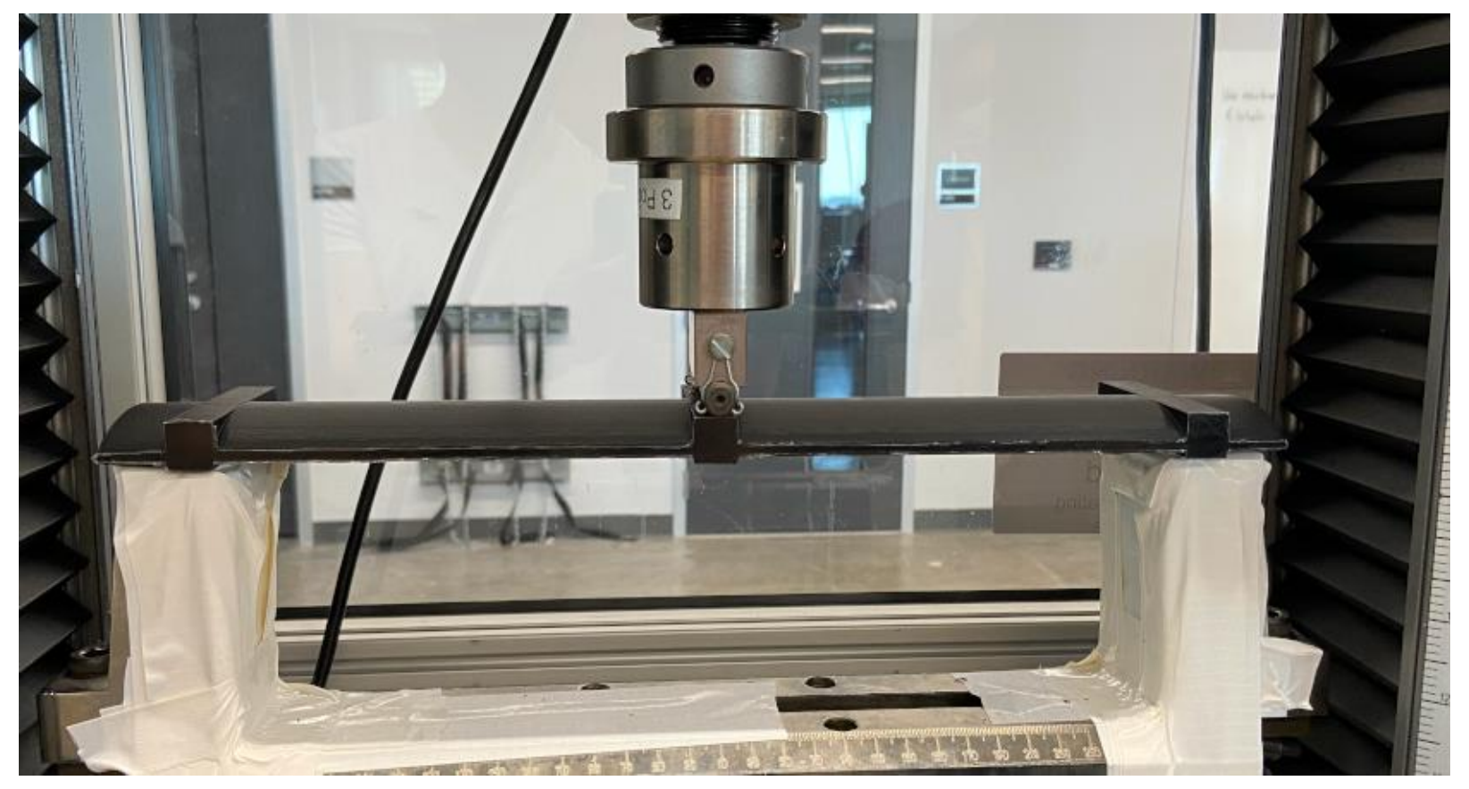

Fig. 5 Three-point bending test setup with sample inserted

CONCLUSIONS

The graphs of the Load vs. Extension curves for the smooth samples show promising results. The samples were able to withstand a significant amount of load for their size. The average flexural extension of the samples before failure was 32.8 mm. The samples had a depth of only around 14 mm, meaning they were able to withstand deformations of over twice their depth.

The samples were also able to withstand significant flexural loads. The average ultimate load that the samples were able to withstand was 580 N. The airfoil cross-section used in these samples was scaled to a 76 mm chord and 14 mm depth and was 3D printed at only 40% infill density. These results show significant load-handling ability for such a small cross-sectional area and infill density.

Though the segmented samples were not able to be fully tested, they were still able to be printed and an attempt to join the segments using resistance welding was made. A metal mesh was placed between the segmented sample and the ends were pressed together as a constant current was applied to the mesh, causing it to heat up. The segments were able to be successfully joined but were slightly misaligned and therefore not tested.

Although further research must still be done in joining the two blade segments and comparing the different segmentation models, these results show promise for a model of joining blade segments that is both structurally sound and viable from a manufacturing standpoint.

Fig. 7 Side View of Smooth Sample (Before Testing)
Adapted from Dongyang Cao

Fig. 8 Side View of Smooth Sample (After Testing)
(Failure Mode: Fiber breakage)
Adapted from Dongyang Cao

FUTURE RESEARCH

Further research topics include continuing the exploration of different segmentation models and structural stability. Plans are already in place to calibrate laboratory equipment used to press the blade segments together.

Once the equipment is properly calibrated, the two blade segments can be aligned and joined with a metal mesh. The metal mesh can be heated with a resistance welding setup to melt the blade ends together and then left to cool into one continuous piece.

Resistance welding works well from a manufacturing standpoint because of its ease of use and the high bond quality developed in the joints. This ensures the segmented pieces of the blades can be successfully joined and stay structurally stable, even under intense flexural loads.

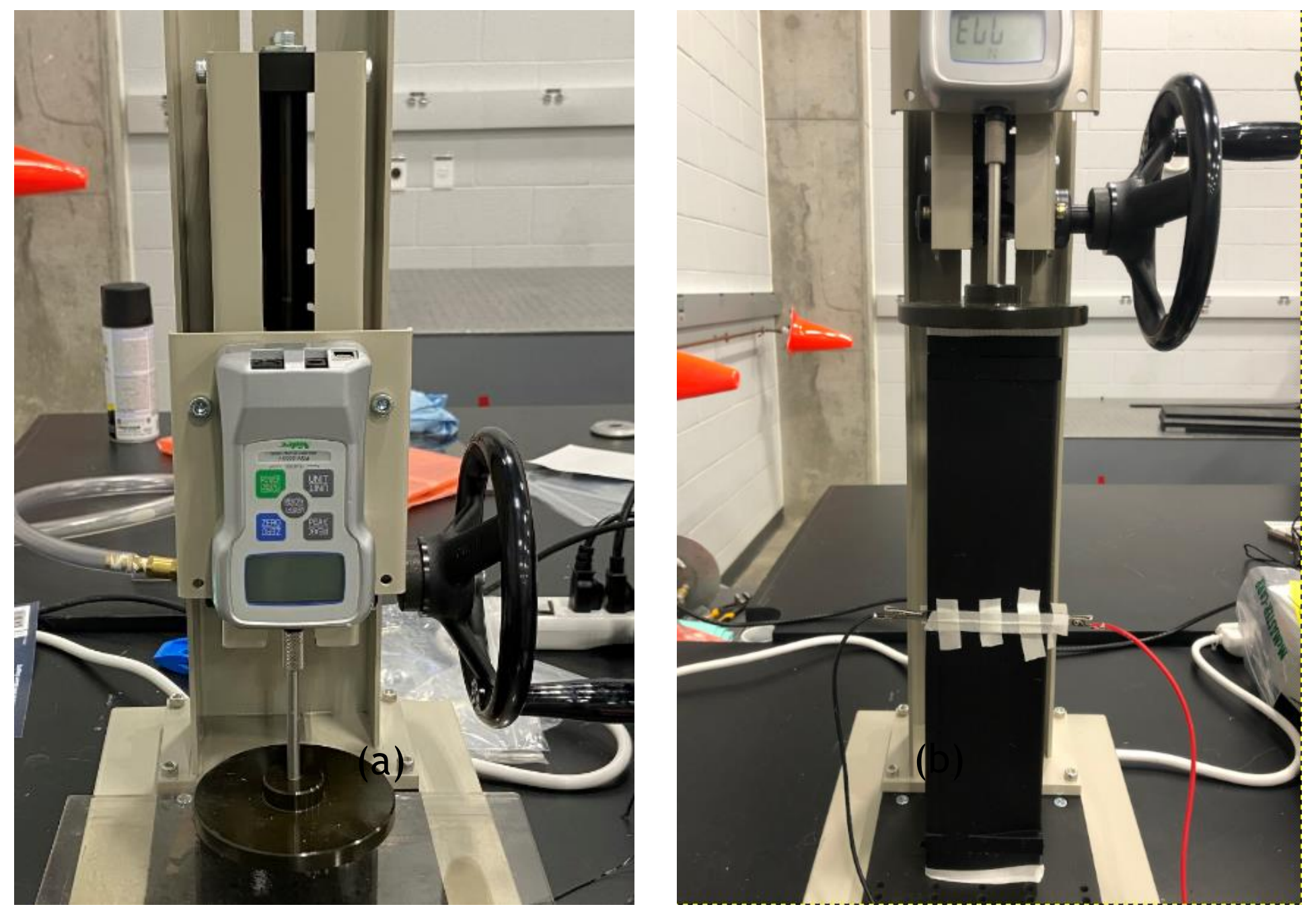

Fig. 9 (a) Resistance welding setup without sample inserted
(b) Resistance welding setup with sample inserted
Adapted from Dongyang Cao

REFERENCES

[1] ASTM D790-15, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials, ASTM International, West Conshohocken, PA, 2015, www.astm.org

[2] Griffith, Daniel, & Richards, Phillip William. *The SNL100-03 Blade: Design Studies with Flatback Airfoils for the Sandia 100-meter Blade.*. United States. https://doi.org/10.2172/1159116

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