Noah Castillo

Group 13

26 February 2025

Anteater Dynamics - 7DOF Robotic Arm

Individual Component Analysis - End Effector Wrist Brackets

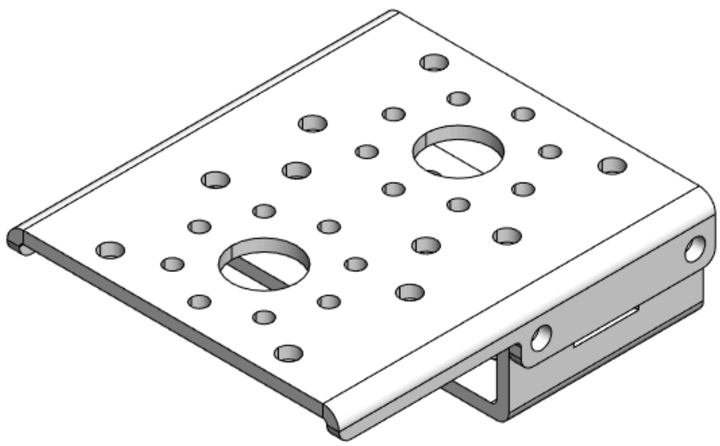


Fig 1. End Effector Wrist Brackets Solidworks Model

The current machine learning research landscape is utilizing robotic systems to collect data on which AI models are trained. Companies such as our industry sponsor, ROBOTIS Inc., provide at-home robotics kits for enthusiasts to collect data and train AI models. Anteater Dynamics seeks to bridge the gap between existing market options by developing a mid-range robotic system integrating Robotis Inc electronics that is capable of 7 degrees of freedom with integrated load sensors to collect critical data for AI training.

One component critical to the success of the overall design is a pair of custom wrist brackets that the team has designed to enable end effector rotation about two perpendicular axis.

The brackets are designed to join two servos, rotating perpendicular to one another, and thereby connect the end effector to the robot linkage. While the component structure is dictated by the fastener requirements of the respective servos, this individual analysis serves to evaluate different material options for manufacturing this custom component. Unlike other off-the-shelf brackets incorporated in this design, this bracket is unique to the Anteater Dynamics Robotic Arm and must be specifically manufactured for this use case. As a result, this analysis will analyze three potential materials, ABS plastic, 5052 Aluminum, and 6061 Aluminum, through material property comparisons and stress and displacement static FEA analysis. The results of this study will inform the team on the viability of additive manufacturing methods and guide future manufacturing of the robotic arm for retail deployment.

The wrist brackets must be manufactured out of a material that is capable of meeting the following functional requirements.

1) The wrist brackets shall be capable of holding the end effector assembly and 400g object without plastic deformation or significant deflection
2) The wrist bracket material shall be capable of supporting threaded screws supporting the two servo motors for extended use periods without deterioration.
3) The wrist bracket shall not experience stresses exceeding the yield stress of the chosen material under maximum load with a 400g object given a load safety factor of 2.

Material	Yield Stress (MPa)	Modulus of Elasticity (GPa)	Density (g/cc)	Material Cost
ABS Plastic	13.0 - 65.0	1.00 - 2.65	1.01 - 1.20	$0.01
5052-H32 Aluminum	193	70.3 GPa	2.68	$0.57
6061 Aluminum	276	68.9	2.70	$0.61

Fig 2. Table Comparing Material Properties and Costs of Potential Materials

- Material properties sourced from MatWeb (Ref1-3)
- Aluminum priced using (Ref-4) per 12”x12” sheet assuming 20 parts cut per sheet
- ABS plastic priced by 4.88g mass (Ref-5)

The table above displays the relevant material properties and material costs per unit (not including labor or machining costs for aluminum) for the three material options. ABS plastic provides a substantial reduction in price when manufactured at scale, and aligns with the larger goal of Anteater Dynamics to provide a robotic arm solution that is available for open source manufacturing. Unlike with aluminum, consumers can create the 3D printed brackets at home without needing a storefront vendor. However, with this advantage comes a significant loss in material yield strength. To determine if ABS plastic is sufficient to meet the functional requirements of the wrist bracket, a static finite element analysis study is conducted to analyze stress and deformation under load.

The load acting on the custom end effector brackets is the weight of the end effector, including the dual XL-430 servo motor, load cells, and custom manufactured parts. The servo motor weight is defined on the supplier website to be 45.36g. The remaining weight is determined using Solidworks mass properties evaluation. The load cells and servo hub are defined as 1060 Al and all other custom parts are defined as ABS plastic.

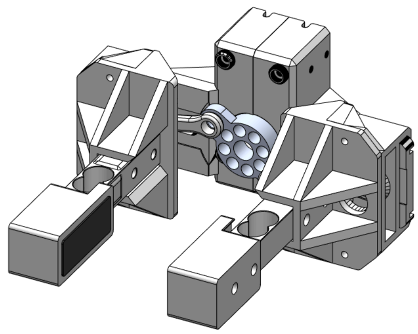
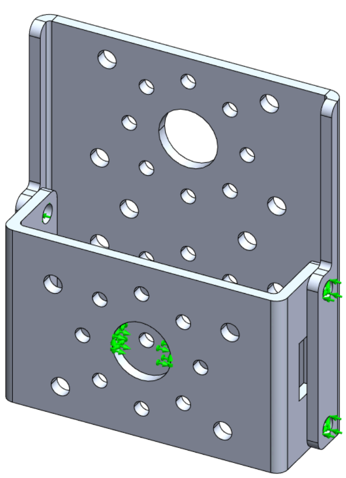


Fig 3. End Effector (without servo) with applied materials for mass evaluation

- End Effector Total Mass: 217.03 g
- Max Object Mass: 400g

<u>Load Case:</u> 12.098 N

- Load with 400g object
- Load factor of 2
- ¼ bearing load applied at four screw holes (3.0245 N each)



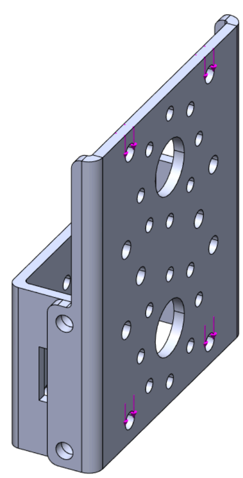


Fig 4 (Left) . Fixed Geometry at Servo Hole and Cylindrical Face Hinge Supports Constraining Radial and Axial Translation

Fig 5 (Right). Bearing Loads on Bracket Screw Holes w/ ¼ of total applied load at each

Results

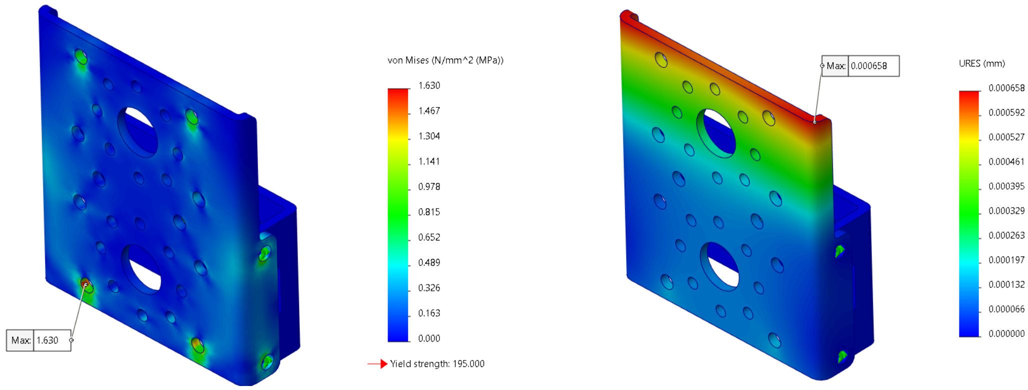


Fig 6. Load Case 01 Stress Plot (Left) and Deformation Plot (Right) of 5052-H32 Al Bracket

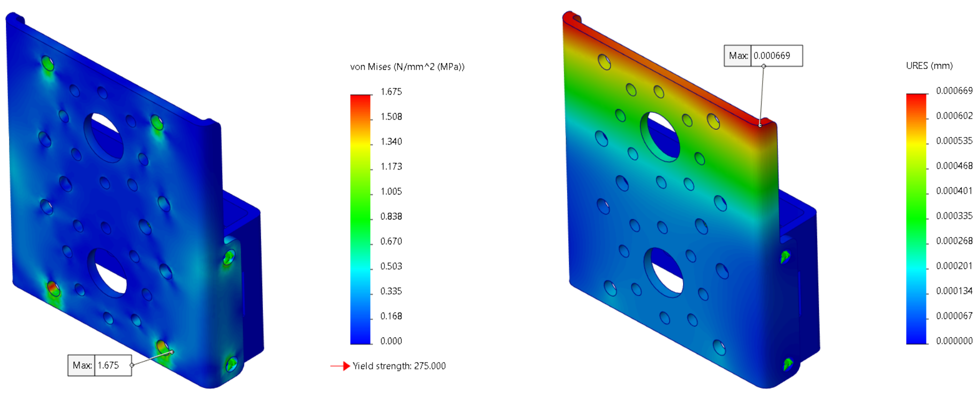


Fig 7 . Load Case 01 Stress Plot (Left) and Deformation Plot (Right) of 6061-T6 Al Bracket

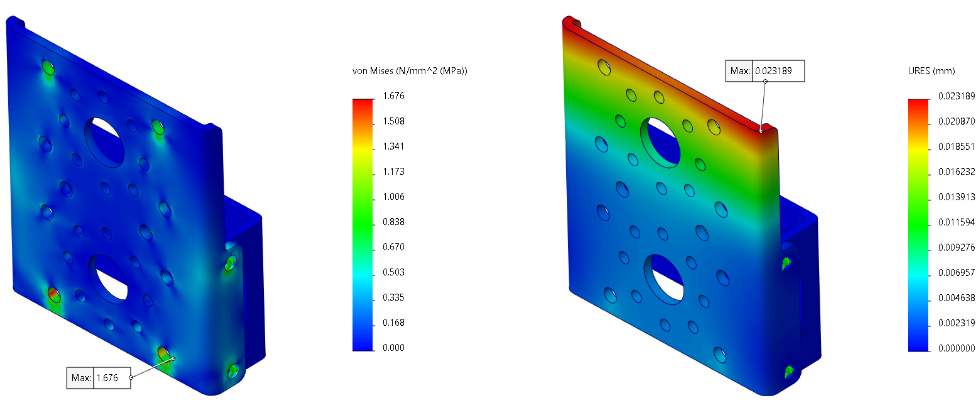


Fig 8. Load Case 01 Stress Plot (Left) and Deformation Plot (Right) of ABS Plastic Bracket

Material	Max von Mises Stress (MPa)	% of Yield Stress	Max Resultant Deformation (mm)
ABS Plastic	1.676	12.9%	0.023189
5052-H32 Aluminum	1.630	0.84%	0.000658
6061 Aluminum	1.675	0.61%	0.000669

Fig 9. Table of Results from Static FEA Analysis

The results of the static analysis show that ABS plastic, despite having the lowest yield strength out of the three material options, only demonstrates a maximum resultant stress of 1.676 MPa, which is is 12.9% of the material yield strength. Elastic deformation using ABS plastic is negligible, totally to 0.023 mm of resultant displacement. 5052 and 6061 Aluminum both exhibited lower maximum resultant stresses than ABS plastic, however, ABS plastic still exceeds the functional requirements set forth for the part. When considering costs alongside these results, ABS plastic becomes the clear best option for manufacturing when considering applied stresses and cost.

The final consideration to satisfy the functional requirements is the ability to hold the screws needed to mount the servo. Case studies conducted on plastic components interfacing with metal fasteners have demonstrated failure on the plastic components as a result of abrasion via the metal fasteners. However, Anteater Dynamics is aiming to provide a mid-range option, not a high-end robotic arm that would price out average consumers. While there is risk of failure in a plastic bracket, solutions such as metal washers and spacers have been proven to increase the lifecycle of plastic components that interface with metal fasteners. The washers and spacers, when applied to all points of fastener contact, help distributed the load and prevent the fastener from acting on the plastic components.

In conclusion, through this analysis it is clear that ABS plastic utilized through additive manufacturing techniques such as 3D printing or injection molding is the material best suited for manufacturing the wrist bracket component for Anteater Dynamics' Robotic Arm. While the plastic may face earlier failure due to fastener abrasion, the satisfactory strength and considerable cost savings along with the implementation of washers and spacers makes ABS plastic the superior material.

Appendix

Ref-1) MatWeb - Material Property Data, Overview of materials for Acrylonitrile Butadiene Styrene (ABS), Extruded, https://www.matweb.com/search/datasheet.aspx?MatGUID=3a8afcddac864d4b8f58d40570d2e5aa&ckck=1

Ref-2) MatWeb - Material Property Data, Aluminum 5052-H32, https://www.matweb.com/search/datasheet.aspx?MatGUID=96d768abc51e4157a1b8f95856c49028

Ref-3) MatWeb - Material Property Data, Aluminum 6061-T6; 6061-T651, https://www.matweb.com/search/datasheet.aspx?MatGUID=b8d536e0b9b54bd7b69e4124d8f1d20a

Ref-4) OnlineMetals.com, https://www.onlinemetals.com/en/buy/aluminum

Ref-5) Business Analytiq, Acrylonitrile butadiene styrene (ABS) price index, https://businessanalytiq.com/procurementanalytics/index/acrylonitrile-butadiene-styrene-abs-usa-price-index-2/

Ref -6) Plastic-Sheets, ABS Advice, http://www.plastic-sheets.co.uk/product-range/abs-advice/

Ref-7) The Madison Group, CASE STUDIES OF PLASTIC FAILURES ASSOCIATED WITH METAL FASTENERS, https://madisongroup.com/wp-content/uploads/2022/09/ANTEC2016JansenPlasticwithMetal-Fasteners.pdf

The primary research focused on finding reliable material data for the materials being considered. When researching, finding websites that met industry standards was an important part of the process. When researching for evidence regarding failure in plastic components, initial results yielded mostly help forums with hobbyists looking for advice. Adjusting the search parameters to specify “case studies” helped yield scholarly articles which would provide reliable information for analysis.