Comparison of strength factors for fused deposition models

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Introduction

Fused deposition modeling, also known as rapid prototyping, is the process of depositing molten plastic filament in layers onto a hotplate in order to create a variety of shapes in short periods of time. The extrusion of the filament and the path it takes directly impacts the performance of the finished part (Bellini & Güçeri, 2003). The increased use of models from rapid prototyping creates a necessity to better understand the strengths and weaknesses of the models. Tensile strength testing is conducted to analyze the Young's modulus and maximum strength. Young's modulus is the measure of stiffness for a material. A higher Young's modulus means a material will exhibit reduced axial deformation for a given force. A material will go through elastic deformation, which is temporary, then plastic deformation, which is permanent, before failure from the increasing force. Maximum strength is the largest stress a material undergoes before failure, but a maximum practical strength is when the assembly fails while experiencing an increasing force. The purpose of this project was to further understanding of the connections of 3D printed assemblies by examining failure points and analyzing tensile strength of such assemblies.

Materials and Methods

A multitude of common fastening designs were researched and used as models to create new designs. Key qualities for a functional assembly were compactness, simplicity, even stress distribution, reversibility, ease of connection and disconnection, and multi-axial stability. Based on these desired qualities, two designs, Lockkey (LK) and SquareSocket (SS), were drawn up and designed in Solidworks®, a 3D designing software. Afterwards, designs were simulated with expected axial forces. Using simulation results, areas of stress concentration and weakness were improved. Completed designs were printed on a Dimension Elite™ 3D printer. To prevent deformation of the samples during the fabrication process, support material was laid, then removed post-fabrication. A total of eight LK assembly samples and nine SS assembly samples were fabricated. A testing procedure was conducted by placing the full assembly within an INSTRON™ tensile tester, pulling apart the assembly, measuring axial force and axial strain. Recorded force and strain were used to graph the stress vs. strain plots of each assembly. Young's modulus was calculated from linear slope of plot and practical maximum strength was found.

Materials and Methods (cont.)

The two key comparisons needed to be made between LK and SS were their Young's modulus and maximum practical strength. These factors are crucial for a functional part. A null hypothesis was established that LK's mean Young's modulus and SS's Young's modulus were equal, with the alternate hypothesis being LK's mean Young's modulus was greater than SS's Young's modulus. The other null hypothesis that was formed was LK's maximum practical strength and SS's maximum practical strength were equal, with the alternate hypothesis being LK's maximum practical strength was greater than SS's maximum practical strength.

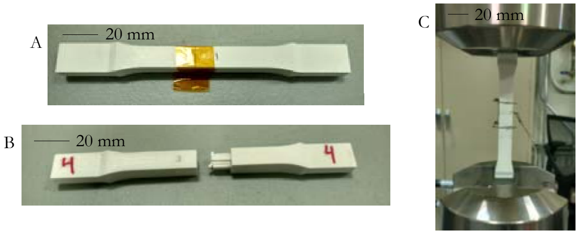
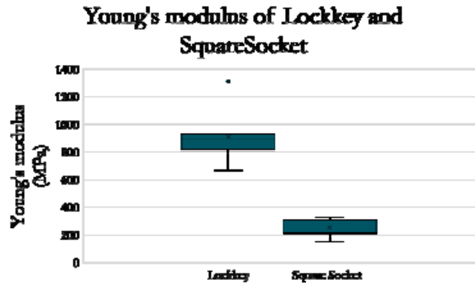


Figure 1: (A) SS sample before testing, (B) SS sample after testing, (C) SS sample in INSTRON™ tensile tester machine.

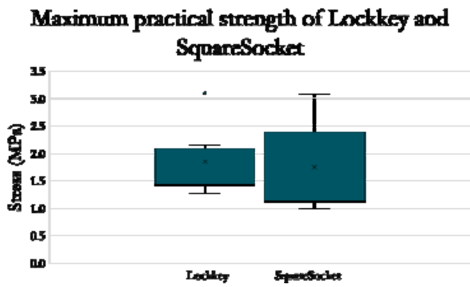
Results

Both factors, Young's modulus and maximum practical strength, for LK and SS were compared using a two sample *t*-test for means with a significance level of $\alpha = 0.05$. There was a significant difference for the Young's modulus in the LK design (M = 906 MPa, SD = 185 MPa) over the SS design (M = 250 MPa, SD = 56 MPa), $t\,(15) = 10.19$, $p < 0.0001$. There was no significant difference for the maximum practical strength in the LK design (M = 1.8 MPa, SD = 0.6 MPa) over the SS design (M = 1.7 MPa, SD = 0.7 MPa), $t\,(15) = 0.33$, $p = 0.373$.



Graph 1 (left): Box-and-whisker plot of the Young's modulus of LK and SS. LK had a sample size of eight and SS had a sample size of nine.

Results (cont.)



Graph 2 (left): Box-and-whisker plot of maximum practical strength of LK and SS. LK had a sample size of eight and SS had a sample size of nine.

Conclusions

The objective of this study was to further understanding of 3D printed assemblies capabilities in tensile strength. Young's modulus and maximum practical strength were comparing factors between the two designs. The results of this study show that assemblies could be designed and fabricated by rapid prototyping techniques that exhibit qualities of a functional fastening assembly. There was a statistical significance that the mean of LK's Young's modulus was greater than SS's mean Young's modulus, while LK's and SS's maximum practical strength had no statistical significance between each other. LK can be considered the assembly that is more resistant to permanent deformation then SS, but otherwise the assemblies are similar in use for practical strength. A future study could be conducted where a scaling factor is introduced to the assemblies, changing the size of the printed assembly may alter performance. A future application of fused deposition modeling to produce fastening assemblies may provide a replacement to common fasteners like nuts and bolts.

References

Bellini, A., & Güçeri, S. (2003). Mechanical characterization of parts fabricated using fused deposition modeling. *Rapid Prototyping Journal, 9*(4), 252-264. doi:10.1108/13552540310489631

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