Transactions on Additive Manufacturing Meets Medicine
Trans. AMMM, Vol 1, No 1, 2019, Article ID S01T05

Infinite Science | Publishing

3D printed structure to replace plaster of Paris in splinting applications, experimental overview

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Abstract: This paper studies the compressive force distribution of a hexagonal pattern on a tubular structure. Variables are the spar and the wall thicknesses, tested cross-axially for both break and yield points. Results are compared to those of plaster of Paris, with the end goal of finding a superior method of creating splints and orthoses for upper limb support.

I. Introduction

We are testing the feasibility of using a 3D printed structure to replace plaster of Paris as the preferred method of casting and immobilizing fractures. This is based on the common knowledge that plaster of Paris splints are time consuming to make, heavy, uncomfortable and soil easily. 3D printed splints on the other hand have the potential to be lighter, stronger and capable of being made without significant manual input.

I.I. Background

This study is a part of a larger system aimed at digitizing and automating the production of upper limb orthoses [1]. Here, we explore the mechanical properties of structures suited to this method for optimal load bearing.

A splint and a full cast have been designed, with positive patient experience in mind. An initial case study used for limb isolation showed a qualitative strength to weight improvement that prompted this study to quantify the mechanical performance.

This study compares this new approach to plaster of Paris, which is still a common use item.

Figure 1: A render of the testing samples that were used, from center to left, the spars get thinner, and from center to right, the wall thickness increases.

Figure 1 shows the 21 samples that were used in this study, the outside tube diameter was 45mm, with wall thicknesses 2-5mm in 1mm increments. The hexagonal features are nominally 12.25mm wide, with the spars thickening from 2-5mm in 1mm increments. Solid tubes of 45mm diameter were also 3D printed with wall thicknesses 1-5mm in 1mm increments.

I.II. Experimental Questions

Figure 2 shows the mechanical properties of layered plaster of Paris casts based on scaled tubes of similar dimensions to our 3D printed ones [2]. We executed a cross-linear bend test as shown in figure 3 to attempt to determine if it is possible to design a 3D printed splint with similar mechanical properties.

Parameter	Group A (2 layer)	Group B (3 layer)	Group C (8 layer)
Weight (gram)	9.16±0.60	17.83±1.14	51.33±20.61
Outer diameter (mm)	29.49±0.52	31.35±0.25	37.73±0.63
Thickness (mm)	1.68±0.23	2.56±0.13	6.21±0.26
Maximum load (N)	29.17±2.63	58.33±4.17	366.67±26.35
Stress (N/mm^2)	0.10±0.01	0.12±0.00	0.29±0.02
Strain (%)	45.15±7.36	59.46±9.30	120.08±5.60
Stiffness (N/mm)	1.17±0.14	2.27±0.29	12.72±1.10
MOE (N/mm^2)	0.0024±0.0004	0.002±0.0001	0.0025±0.0002

Figure 2: Is an excerpt from the paper [2] which is proving the figures for plaster of Paris, until the figures will be verified with our own testing.

II. Material and methods

The material used was Acrylonitrile butadiene styrene, ABS, a common material in the Material Extrusion, ME, method for 3D printing polymers. ME was chosen as a commonly available, low-cost technology (Zortrax m200) with ABS as a material commonly used for products that contact with the human body[3].

The cross-linear 3-point bend test was performed on an Instron 10k (5966).

DOI: 10.18416/AMMM.2019.1909S01T05

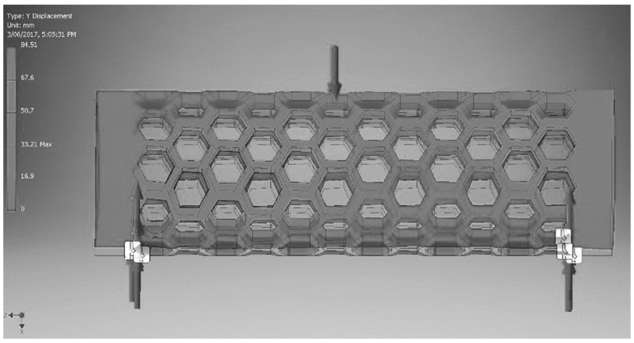

Figure 3: Simulated example of the load points for the mechanical testing of the samples.

III. Results and discussion

Shown in Table 1 are the values for the break and yield forces for each sample made. The data shows an interesting trend, shown in Figure 4.

Table 1: sample loads at break and Yield. Values in N. BT is spar thickness (in mm, BT0 is solid), WT is wall thickness in mm

Sample	Load @ break	Load @ yield
hex_BT0_WT1	224.220	264.789
hex_BT0_WT2	777.5	820.205
hex_BT2_WT2	0.225	91.389
hex_BT3_WT2	96.630	74.336
hex_BT4_WT2	141.813	148.804
hex_BT5_WT2	157.632	193.195
hex_BT0_WT3	913.299	913.360
hex_BT2_WT3	145.447	146.853
hex_BT3_WT3	129.489	138.250
hex_BT4_WT3	256.848	302.629
hex_BT5_WT3	376.931	407.0174
hex_BT0_WT4	1582.416	1582.416
hex_BT2_WT4	211.717	214.036
hex_BT3_WT4	146.906	183.588
hex_BT4_WT4	458.183	474.440
hex_BT5_WT4	455.991	569.898
hex_BT0_WT5	2696.825	2698.004
hex_BT2_WT5	255.519	272.833
hex_BT3_WT5	203.126	232.709
hex_BT4_WT5	593.869	602.756
hex_BT5_WT5	745.004	745

The most obvious result is an exponential trend between the weight of the samples and the load that they can withstand. Furthermore, the wall thickness to achieve these mechanical results are a lot more predictable and can also be a lot smaller than for the same loads in plaster of Paris.

Using the results obtained, we are able to select design parameters for applications, below are three of the results that were found that gives a resultant weight to load characteristic.

- Hex_BT0_WT5 mm 78g 2698N
- Hex_BT4_WT3 mm34g 302.63N
- Hex_BT2_WT2 mm19g 91.39N

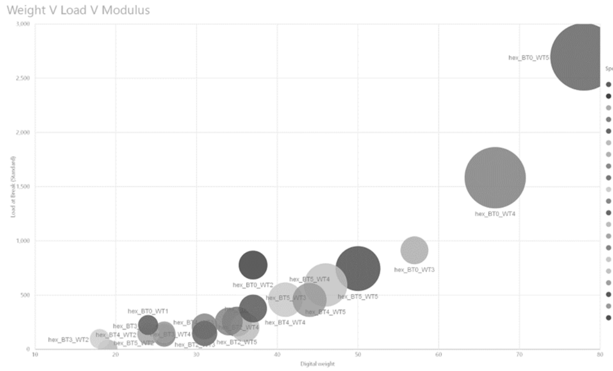

Figure 4: Weight on the x-axis, Load on the y-axis, and the modulus as the size of the circle.

The third example shows 91N, which might not be a huge breaking force. However, this might be suitable for a small child, and the weight and size reductions will potentially lower the effect of the cast on normal life during the recovery period. Compared to a similar weight plaster example, there is a load gain of 31N, which equates to an 11.7% heavier but 57% stronger example.

IV. Conclusions

This study acts as a design aid that can be used to determine the weight and dimensions for required loads of the orthoses. We were able to gain good insight as to where the designs should be heading, and which design parameters should be focused on.

Further publication work is ongoing to compare the 3D printing technique used to other forms of casting, like manually formed thermoplastic splints as well as more comprehensive analysis of the experimental data. Further work can include studying the effects of varying the cell dimensions to achieve optimal protection for the wearer with minimum weight impediment.

Author's statement

Research funding: The author states no funding involved. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent is not required in this portion of the study. Ethical approval: The research related to human use has not been scoped for this study yet, this is a pre-clinical / material study. Future work will be completed under the correct ethical approvals in the country of which the study takes place.

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