BDL/Aneuvas 3D Print Testing

Project Management Assignment

Isaac Smith

Luke Nelson

Kathryn Nelson

Aditya Ponugupaty

2021-2022

Project Sponsor: Aneuvas Technologies Inc.

Sponsor Mentor: Timothy Becker, PhD.

Instructor: David Willy, Senior Lecturer

TABLE OF CONTENTS

Contents

1 Reflection (Isaac)

1.1 Successes

The team constantly kept in communication via group chat, team meetings, and about scheduling conflicts, tests, and other items from courses that would interfere with an assignment or meeting. All assignment sub-items that were assigned to different members got completed in a timely fashion. In addition, the team was very open to helping one another out, editing, and working together to complete projects – even late into the evening. Testing was often conducted over the weekend(s) and was well communicated and attended.

- Communication
- Planning
- Testing
- Accountability
- Responsibility

1.2 Room for Improvements

The team in general did very well. Some items that could improve would include planning of specific tests (procedures) or ensuring that proper equipment is available for the testing. This is primarily related to printing and soaking the testing samples on time. Ensuring that the rheometer is not in use ahead of time is one item of improvement.

- Testing procedures
    - Team lead will come in up to an hour ahead of schedule and set up the rheometer and equipment. Coordinate equipment usage with the lab lead and other outsourced equipment with the proper department contact (fluoroscope use).
- Equipment planning
    - Team lead will contact other lab members via proper channels to ensure equipment availability prior to the team's need.
- Sample printing / soaking
    - Team testing manager will plan with the team lead to print and soak samples 4 days prior to testing (4 days of a soak is required per testing SOPs). Additionally, samples can be mass printed ahead of time and soaked when needed.

1.3 Remaining Design Efforts

- Print all samples needed.
- Test samples in their respective tests in accordance with BDL SOPs.
- Cumulate data in Excel.
- Client presentations/updates of data collected.
- Select final material mesh setting.
    - i.e., Will we use 30-50, 40-60, or a different combination based on the data from 30-50 and 40-60 testing.

- Adjust the Circle of Willis model to new layered settings.
- Clean model(s) and confirm flow ability with a flow pump.

2 Gantt Chart

We kicked off this semester by contacting our client, Dr. Becker, to start off a plan for our testing and analyzing the data for our project. Since our project revolves around a more of a design of experiments-based system, we were asked by our client to do eight individual tests for different samples with different hardness values. So, the test days were implemented in the Gantt Chart (Appendix A) and it will primarily be on Saturdays with an additional day of testing on Monday to finish collecting data and compiling them together for visual representations. The beginning will be compromised of solely testing and we wish to finish at least a total of five tests by hopefully the beginning of the first hardware test at the 33% mark. Even though we want to finish s twice the percentage of what Dr. willy is asking us, we feel getting all the data first is important to assess the material and implement it into the system. We will also use the tests in our project as our individual analysis assignments to help us boost our knowledge into the different variables to manipulate our material efficiently. We will start off with the Hardness and Poisson's Ratio test beginning on the first week and go into radial force tests and compile all of them for that week. We will then discuss with our client for the fifth test and it will either be Lubricity or Compression depending on what he feels is important to find. Overall, we will have a major testing phase in the beginning as we have nothing to manufacture, which will give us more time to analyze the data midway through and hopefully with a few tweaks get a working system running by spring break to get it approved by the client and add additional capabilities to our device.

3 Purchasing Plan (Kathryn)

Halfway through last semester, our team started printing and testing samples. Because of this part of our budget has already been spent on renting the equipment needed to print and test the samples. We started with a budget of $1000 and ended last semester with $721.85. Most of the budget so far has been spent on renting the rheometer, which is $20/hour, and we spent a total of 13 hours on testing last semester. A total of $18.15 was spent on materials with 32 grams of Agilus 30 costing about $0.25/gram, 2 grams of VeroClear costing $0.20/gram, and 65 grams of support material costing about $0.15/gram. All purchases and renting of equipment are made through the BDL lab on campus, but the materials are sourced from Stratasys.

BDL/Aneuvas 3D Testing Capstone

				TIME OF RHEOMETER		MATERIALS				OTHER				BALANCE
TASK	DESCRIPTION	START DATE	END DATE	HR	$/HR	AGILIUS (g)	$/PER GRAM (A)	VEROCLEAR (g)	$/PER GRAM (V)	SUPPORT (g)	$/PER GRAM (S)	MISC.	SPENT	REMAINING
PROTOTYPES	SIZE / RATIO OF THE MATERIALS USED	-	-	-	$ 20.00	-	0.25	-	0.2	-	0.15		$ 1,000.00	$ 1,000.00
SAMPLES FOR PRACTICE	AGILIUS 30	2-Oct	2-Oct	0.0	$20.00	30.0	0.25	0.0	0.2	60.0	0.15		$ 16.50	$ 983.50
PROTOTYPE 1	AGILIUS 30 & VEROCYAN (shear test)	24-Oct	24-Oct	8.0	$20.00	2.0	0.25	2.0	0.2	5.0	0.15		$ 161.65	$ 821.85
Subtask	Compression test	13-Nov	13-Nov	5.0	$20.00	0.0	0.25	0.0	0.2	0.0	0.15		$ 100.00	$ 721.85
SubTask					$20.00		0.25		0.2		0.15		-	-
SubTask					$20.00		0.25		0.2		0.15		-	-
SubTask					$20.00		0.25		0.2		0.15		-	-
SubTask					$20.00		0.25		0.2		0.15		-	-
Task					$20.00		0.25		0.2		0.15		-	-
Task					$20.00		0.25		0.2		0.15		-	-
SUBTOTAL					$260.00		$8.00	2.0		65.0	$ 1.35		$ 278.15	$ 721.85

Figure 1: BDL/Aneuvas 3D Capstone Budget

For this semester, most of our remaining budget will go towards renting the rheometer, roughly 80% of the remaining budget. The rest will go into printing out any remaining samples that we would need for testing as well as any remaking of old samples that might've been damaged or lost.

4 Testing Analysis Plan (Isaac, Luke, Kathryn)

4.1 Tests and Relations

Listed below are the tests being conducted by Team BDL/Aneuvas in accordance with the initial project proposal and standard operating procedures (SOPs) used by BDL for each test. The SOPs help to ensure the quality and replicability of tests being conducted. The customer requirements and engineering requirements (CR/ERs) are in accordance with the client meetings, House of Quality, and design analysis conducted Fall 2021. The SOPs are multi-page procedures provided by BDL and are being summarized below. These SOP synopses and ER/CRs met are from our Final Proposal Report Fall '21, where each the original five tests are discussed in more detail.

4.1.1 Shear Test

4.1.1.1 CR/ERs Met

Our design has been supported by the results of the shear tests. If we see the shear charts which compare it to donor tissue in Appendix C, the shear values for both ratios are significantly greater than the donor tissue that we are comparing to, but they are almost half the values of previous studies using a 50-50 ratio and Agilus40 (mixed with veroclear to get that hardness value). The results of our study validate that our design is feasible by comparing the mechanical properties of the donor research with our studies. By varying the ratios of the polymers, it is possible to tweak the mechanical properties and even mimic the mechanical properties of human tissue. Several of our clients' requirements have been met here, including the specimen retaining its shape after testing, using the right material to make the specimen our clients wanted, and becoming closer to being like organic tissue [1].

- Shear Modulus (KPa)
- Frequency (rad/s)

4.1.1.2 Standard Operating Procedure(s)

To perform this test, a small piece of sandpaper will be placed into the rheometer and a disk sample will be placed on top of it. The rheometer will then apply a continuous oscillating force or direct shear to the sample. By measuring the shear modulus of the sample, it can be compared to the shear properties of human vessels and changes can be made accordingly [1][2].

4.1.2 Compression Test

4.1.2.1 CR/ERs Met

The results of the compression tests will validate that our design is feasible by comparing the mechanical properties of the donor research with our studies. By varying the ratios of the polymers, it is possible to tweak the mechanical properties and even mimic the mechanical properties of human tissue. Several of our clients' requirements have been met here, including the specimen retaining its shape after testing, aiming for a specific compressive modulus, using the right material to make the specimen our clients wanted, and becoming closer to being like organic tissue [1].

- Compressive Modulus (KPa)
- Frequency (rad/s)

4.1.2.2 Standard Operating Procedure(s)

To perform this test, a small piece of sandpaper will be placed into the rheometer and a disk sample will be placed on top of it. The rheometer will then apply an axial force of 0.9-1.4 N onto the sample, measuring how resistant the sample is to the force. By measuring the elastic modulus of the sample, it can be compared to the shear properties of human vessels and changes can be made accordingly [1][2].

4.1.3 Lubricity Test

4.1.3.1 CR/ERs Met

The results of the lubricity tests will validate that our design is feasible by comparing the mechanical properties of the donor research with our studies. By varying the ratios of the polymers, it is possible to tweak the mechanical properties and even mimic the mechanical properties of human tissue. Several of our clients' requirements have been met here, including aiming for a specific Poisson ratio, using the right material to make the specimen our clients wanted and becoming closer to being like organic tissue [1].

- Coefficient of Friction

4.1.3.2 Standard Operating Procedure(s)

Before the test can proceed, a table must be placed perpendicular to the rheometer with a plastic container containing a 3D printed wheel placed some distance away, the desired distance of the container changes depending on the sample, and a clamp on the clamped to the other end of the table. A syringe filled with water will be used as a weight and will freely hang off the clamp when the wire is tied to it. A tube-shaped sample is secured to the wheel and surgical wire is connected to the rheometer, through the sample and connected to a syringe, creating two triangle shapes. Once everything is set up, the test can begin. The rheometer will gently pull on the wire and measure the amount of resistance the wire is experiencing while moving, allowing the friction of the interior of the sample to be found. By finding the friction property of the sample, it can be compared to the friction property of the human vessels to see if there are any similarities or if any changes need to be made to help the sample values get closer to the human values [1][2].

4.1.4 Compliance Test

4.1.4.1 CR/ERs Met

The results of the compliance tests will validate that our design is feasible by comparing the mechanical properties of the donor research with our studies. By varying the ratios of the polymers, it is possible to tweak the mechanical properties and even mimic the mechanical properties of human tissue. Several of our clients' requirements have been met here, including the specimen retaining its shape after testing, using the right material to make the specimen our clients wanted, and becoming closer to being like organic tissue [1].

- Compliance (cm^3/mmHg)
- Pressure (mmHg)

4.1.4.2 Standard Operating Procedure(s)

To perform this test a tube-shaped sample will be secured a pressure transducer and syringe, one on either side. The sample will be filled with thick liquid until there is no air left inside and placed under the fluoroscope. Slowly fill the sample with more liquid until the pressure gage reads 80mmHg, take a picture with the fluoroscope and then increase the pressure by 40mmHg, take another picture. Repeat this step until the pressure has reached 280mmHg. Send the images taken during this process to the rheometer in the lab. This helps see how much the sample can swell from internal pressure. By doing this procedure, the compliance properties of the sample can be compared to the properties of the human vessel and necessary changes can be made [1][2].

4.1.5 Tension Test

4.1.5.1 CR/ERs Met

The results of the tension tests will validate that our design is feasible by comparing the mechanical properties of the donor research with our studies. By varying the ratios of the polymers, it is possible to tweak the mechanical properties and even mimic the mechanical properties of human tissue. Several of our clients' requirements have been met here, including the specimen retaining its shape after testing, aiming for a specific stiffness value, using the right material to make the specimen our clients wanted, and becoming closer to being like organic tissue [1].

- E (KPa)
- ω (Rad/s)

4.1.5.2 Standard Operating Procedure(s)

To perform this test, a rectangular sample is secured in the rheometer and pulled until it experiences an axial force of 100mHg. The procedure is done again but this time the sample will experience an axial force of 160mmHg. Measuring the tension properties of the samples informs the team on how close the prototypes are to the properties of human vessels [1][2].

4.1.6 Hardness Test

4.1.6.1 CR/ERs Met

The results of the hardness tests will validate that our design is feasible by comparing the mechanical properties of the donor research with our studies. By varying the ratios of the polymers, it is possible to tweak the mechanical properties and even mimic the mechanical properties of human tissue. Several of our clients' requirements have been met here, including the specimen retaining its shape after testing, aiming for a specific stiffness and compressive modulus values, using the right material to make the specimen our clients wanted, and becoming closer to being like organic tissue [1].

- Modulus (KPa)
- Strain (%)

4.1.6.2 Standard Operating Procedure(s)

To perform this test, a metal ball is attached to the 8mm plate to create an indenter. The rheometer is then loaded to 0.9-1.0N of Force. The researcher then conducted the test by allowing the rheometer to compress the sample at a given rate. The release of energy as the sample is destroyed is recorded for the sample hardness [1][2].

4.1.7 Poisson's Ratio Test

4.1.7.1 CR/ERs Met

The results of the compliance tests will validate that our design is feasible by comparing the mechanical properties of the donor research with our studies. By varying the ratios of the polymers, it is possible to tweak the mechanical properties and even mimic the mechanical properties of human tissue. Several of our clients' requirements have been met here, including the specimen retaining its shape after testing, aiming for a specific Poisson's ratio, using the right material to make the specimen our clients wanted, and becoming closer to being like organic tissue [1].

- Poisson's Ratio (Unitless)

4.1.7.2 Standard Operating Procedure(s)

To perform this test, the rheometer is equipped with DinoCapture and a mirror plate. The sample is placed in the center of the camera field of view and the camera is calibrated based on known measurements. The sample is then compressed with a known force over a known period. Axial displacement is measured by the calibrated DinoCapture program and results are filled into Excel for analysis. The sample must be wicked around with PBS to ensure that it stays wet and the bottom that touches the glass is clearly visible to the camera [1][2].

4.1.8 Radial Force Test

4.1.8.1 CR/ERs Met

The results of the radial force tests will validate that our design is feasible by comparing the mechanical properties of the donor research with our studies. By varying the ratios of the polymers, it is possible to tweak the mechanical properties and even mimic the mechanical properties of human tissue. Several of our clients' requirements have been met here, including the specimen retaining its shape after testing, aiming for a specific radial force, using the right material to make the specimen our clients wanted, and becoming closer to being like organic tissue [1].

- Radial Force (N/mm)

4.1.8.2 Standard Operating Procedure(s)

To perform this test, a tube sample is placed centered on the rheometer. The gap must be set to touch the top of the tube. Then the rheometer will compress the tube to 50% of the total exterior diameter. The radial force is determined by dividing the force at 50% compression by the length of the tube [1][2].

5 Capstone Proposal Section

Team BDL/Anuevas proposes to have the data accumulated throughout this semester of testing be taken into consideration for each check in assignment (33%, 60%, 100%). As well as the final product being the circle of Willis but modified with what materials the team decided based on the research conducted and anatomically similar dimensions for the 100% check in; providing the reports, data, and researched based reasoning to our design choice of course.

A note of previous mention and what our team did and could help another team:
Adjusting the individual analysis to allow for the number of analytical / mechanical tests being conducted to be used by team members. For example, one member does Poisson’s ratio and Tension, while another conducts research into Shear and Compression testing. We had a set of data from compression and shear that we used as proof of concept that could be applied to how the material may react under other tests due to time constraints.

For example, testing shear and compression as proof of concept to prove that it's worth conducting other tests. Then applying that to what we may expect to see in other tests, such as lubricity or tension. The following semester provides more time to conduct client approved tests and build onto the previous assignment in a manner that meets the client requirements. This better shows the progression of design, proof of concept, testing, and results. It is also more feasible for a team to conduct the tests given more time. For us, each test is/was about 3-5 hours plus Excel analysis.

6 References

[1] I. Smith, L. Nelson, K. Nelson, and A. Ponugupaty, "Final Proposal," Rep. Nov. 2021.

[2] N. G. Norris, W. C. Merritt, and T. A. Becker, "Application of nondestructive mechanical characterization testing for creating in vitro vessel models with material properties similar to human neurovasculature," *Journal of biomedical materials research. Part A*, 17-Sep-2021. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/34617389/. [Accessed: 13-Oct-2021].

7 Appendix

7.1 Appendix A: Gantt Chart

BDL/ANEUVAS CAPSTONE Semester 2

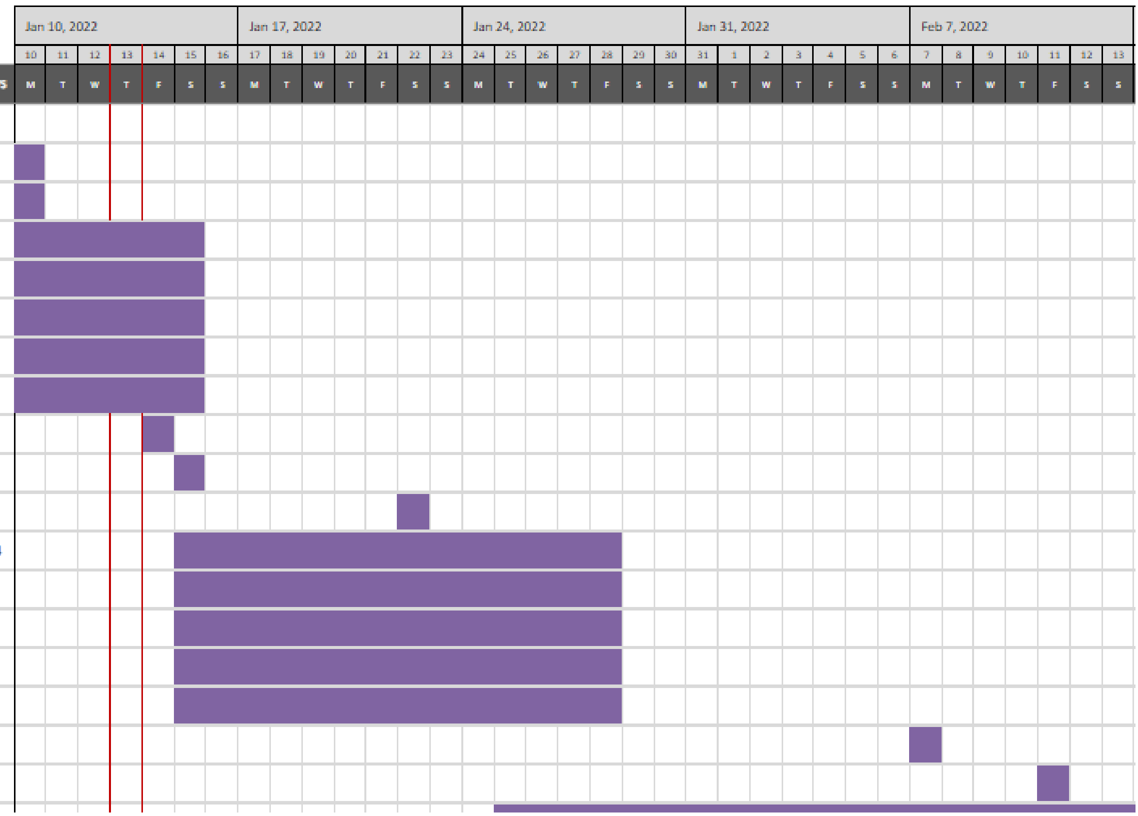
NAU ME Capstone
Project Lead: Isaac Smith

Project Start: Mon, 1/10/2022

Display Week: 1

** As of date of making

TASK	ASSIGNED TO	PROGRESS	START	END	DAYS
Semester 2 Start-up					
Talk to client	All		1/8/2022	1/10/2022	3
Delegate testing days until first hardware satus update	All		1/10/2022	1/10/2022	1
Project Management Assignment	All		1/10/2022	1/15/2022	6
Reflection	Issac		1/10/2022	1/15/2022	
Gantt Chart	AP		1/10/2022	1/15/2022	
Purchasing Plan	Katheryn		1/10/2022	1/15/2022	
Testing Analysis Plan	All		1/10/2022	1/15/2022	
Hardness and Poission's Ratio test day	All		1/14/2022	1/14/2022	
Radial Force Test Day	All		1/15/2022	1/15/2022	
Lubricitity or Compression Test Day (Based on clients approval)	All		1/22/2022	1/22/2022	
Individual Analytical Analysis	All		1/15/2022	1/28/2022	14
Solidworks Self Learning	Issac		1/15/2022	1/28/2022	
Possion's Ratio Analysis	AP		1/15/2022	1/28/2022	
Radial Force Anaysis	Katheryn		1/15/2022	1/28/2022	
Hardness Analysis	Luke		1/15/2022	1/28/2022	
Hardware Status Update	All		2/7/2022	2/7/2022	
Peer Eval 1	All		2/11/2022	2/11/2022	



7.2 Appendix B: Client Testing Approval

Material Testing Capstone Inbox x

Isaac Smith <ijs38@nau.edu> Fri, Jan 7, 6:29 PM (5 days ago)
to tim.becker

Good evening Dr. Becker,

For the capstone project, my team is being asked to provide an email from our client approving the tests we will be conducting this semester.
The tests planned to be conducted for the material testing are currently:
Shear, Compression, Tension, Lubricity, and Compliance. This is for the 80% / 20% layered pusks we conducted the shear and compression tests on.

Can you please confirm the approval of these tests to be conducted and clarify if any additional tests are needed? Hardness, for example, was one test that was "iffy" on if we would conduct it.

Thank you very much for your time and consideration.

Very respectfully
Isaac Smith

--
Isaac Smith
BS Student, *Mechanical Engineering*
Research Assistant, *Bioengineering Devices Laboratory*
Northern Arizona University

Timothy A. Becker Sat, Jan 8, 12:36 PM (4 days ago)
to me

I approve the tests you mentioned. Hardness should be considered, as well as Poisson"s Ratio and Radial Force. Was there a reason we weren't going to have you do these?

Do I need to send something to David Willy once we have agreement?

DrB

Tim Becker, PhD
Associate Professor
Isaac Smith <ijs38@nau.edu> Jan 8, 2022, 4:19 PM (4 days ago)
to Timothy

Hey Dr Becker,

So the original proposal submitted to capstone has:
" Biaxial vascular tension of materials
o Blood vessel compliance
o Lubricity of model interior
o Compressive and Shear Modulus"

I'm sure we could add in Poisson' Ratio pretty easily. Radial force was said to be changing or changed so I was unsure. Hardness was not included just because it was not listed in the proposal. Outside of that rationale, I'm not sure how the proposal and selected tests were chosen.

You don't have to send Willy anything, I just have to take a screenshot of the final email with your confirmation of the tests in it. The screenshot is being attached to an assignment Willy gave the classes. He included it to try to help make capstone assignments more open to analytical projects.

Very respectfully,
Isaac Smith

...

Timothy A. Becker Jan 8, 2022, 4:33 PM (4 days ago)
to me

All of these tests are referenced and published in Nick's manuscript that came out this Fall (BDL-papers/BDL published). Good research/projects dictates that you use these published testing standards on new materials as well, so they can be compared. The only exception is when you come up with a better testing scenario to replace an old one...

Since hardness, radial force, poison's ratio are all defined-they should be repeated for comparison, using the manuscript's guidance (... from the Methods section...).

DrB

Tim Becker, PhD
Associate Professor

7.3 Appendix C