

**PRAIRIE VIEW A&M UNIVERSITY
ROY G. PERRY COLLEGE OF ENGINEERING
DEPARTMENT OF CHEMICAL ENGINEERING
CHEG4310P23 Polymer Science and Engineering, SPRING 2022**

I. COURSE SYLLABUS IN ABET FORMAT

II. ASSESSMENT RESULTS FOR CURRENT AND PAST THREE PERIODS

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Original Test Questions & Master Solution/grading scheme used

(Summary of topics can be a separate page or include on the assignment itself)

Above Average (Graded original work)

Average (Graded original work)

Below Average (Graded original work)

IV. QUIZ

Summary of Topics covered by Homework

Original Homework Questions & Master Solution/grading scheme used

Above Average (Graded original work)

Average (Graded original work)

Below Average (Graded original work)

V. PROJECT

Summary of Topics Covered by Project

Project Problem Statement and Grading Scheme

Above Average (Graded original work)

Average (Graded original work)

Below Average (Graded original work)

Course Description in ABET Format

I. COURSE DESCRIPTION IN ABET FORMAT

COURSE SYLLABUS

CHEMICAL ENGINEERING DEPARTMENT CHEG 4310 P23 ST-Polymer Science and Engineering

1.	Course number and name:	CHEG 4310 P23 ST-Polymer Science and Engineering
2.	Credits and contact hours:	3 credit hours; 5 contact hours
3.	Instructor's or course coordinator's name:	Dr. Nabila Shamim
4.	Text book: Title:	Polymer Science and Technology 2nd edition Joel R.Fried ISBN: 013-018168-4 Principles of polymer engineering 2nd edition, N. G. McCrum , C. P. Buckley, C. B. Bucknall Oxford science publication ISBN-13: 978-0198565260
	Author:	Joel R.Fried
	Publisher, Year & Edition:	Prentice-Hall, (2nd Edition).
5.	Specific course information	
	a. Brief description of the content of the course (catalog description)	(3-0) Credit 3 semester hours. The course involves a combination of lecture, presentation, and laboratory experience. The learning opportunity typically involves a topic that is of infrequent interest.
	b. Prerequisites or Co-requisites	CHEM 2303
	c. *Indicate whether a required, elective, or selected elective (as per definition provided) course in the program	Required
6.	a. Specific goals for the course specific outcomes of instruction (e.g. The student will be able to explain the significance of current research about a particular topic.) <i>Students will be able to :</i>	b. Explicitly indicate which of the student outcomes listed in Criterion 3 or any other outcomes are addressed by the course. <i>The specific goals for the course specific outcomes listed on the left column will address the following student learning outcomes:</i>
	(i) Understand and describe the manufacture (using both traditional and non-traditional synthesis schemes) of commercially important polymers using concepts from chemical kinetics and equilibrium thermodynamics. (ii) Design and optimize 3D printed structure, and nanofibers (iii) Describe polymer behavior using basic Maxwell's theory of viscoelastic polymers. (iv) Understand the structure of polymers in	Outcome D1 An ability to identify, formulate, and solve engineering problems by applying principles of engineering, science, and mathematics. 1. Conduct, summarize and/or present a comprehensive literature review in the topical area 2. Participate in a laboratory experience that requires application of chemical engineering principles 3. Analyze the literature in an emerging engineering area 4. Apply Maxwell equation for viscoelastic materials

	the solid state and describe the effects of structural organization (i.e., crystallinity, liquid crystallinity, phase separation) on molecular and end use properties of polymers, and recognize the basic stress/strain and viscoelastic behavior of polymers based on a knowledge of structure and thermal properties (e.g., melting and glass transition) and apply the Boltzmann superposition principle and Williams-Landel-Ferry equation to predict viscoelastic behavior of polymeric melts.	5. Present projects and results in a format acceptable for publication/presentation
7	Brief list of topics to be covered	1. Introduction, the nature of polymeric materials (3 hours) 2. Polymer Synthesis (6 hours) 3. Kinetics of Step-Growth and Addition Polymerization (9 hours) 4. Laboratory Experiment on 3D printing Project 1 (6 hours) 5. Crystallization, Melting and Glass Transition (6 hours) 6. Laboratory Design Experiment (9 hours)

Prepared by: Dr. Nabila Shamim

Date: May 20, 2022

II ASSESSMENT RESULTS FOR CURRENT AND PAST THREE PERIODS

Program Outcomes Assessed in this course

Outcome D1:

An ability to identify, formulate, and solve engineering problems (CEP) by applying principles of engineering, science, and mathematics.

Assessment Summary of Class Semester Averages for Outcomes (Should be provided for Fall 2019 through Spring 2022 Assessment Period)

Outcomes	D1
Semester	Semester Class Average (%)
Spring 2022	85
Comments on Trend of Data (Improving or deteriorating)	The average outcome of this course. This is the first time the elective course is taught in the spring 2022 semester.

*Expected Semester Class Average = 70% (or as defined by the program)
Ideal Semester Class Average = 75% (or as defined by the program)

End of Semester Course Assessment Reports Spring 2022 and Last Three Assessment Periods.

Each summary contains the following Information

1. Performance Statistics

- Total number of students in class
- The class average performance (**stated as %**) in each course outcome assessed in this class and the **two previous times course was assessed**.
- The acceptable class average for the class in each outcome area as set by your department.
- Percentage of students who scored below the expected average in each outcome.

2. Implementation Summary

- Brief summary of plans implemented during the semester based on last assessment report

3. Perceived Problems

- Instructor's critical **evaluation** of perceived problems that affected students' performance. **Realistic problems should be identified throughout the semester and summarized in this section of the report.**

4. New Plans for Addressing Problems

- Instructor's plans for addressing the perceived problems the next time the class is taught. **These should be specific enough for another instructor to implement. Most of these should be things that, you, the instructor can implement to help students to improve. Be creative.**

5. Overall Trend over last three assessment periods

- Instructors' summary of overall performance trend for each outcome measured over the last three periods.

5. Were Expectations Met?

- Answer **YES** if the **class average was above the expected average** and the **stated percentage of students** scored at or above the expected average, else answer **NO**.

Table 2.1 END OF SEMESTER COURSE OUTCOME ASSESSMENT REPORT
CHEG 4310 P23 ST-Polymer Science and Engineering: SRPING 2022 SEMESTER
Report Prepared by: Dr. NABILA SHAMIM Report Date: May 18, 2022

Semester	Analysis Type	Number of Students	Outcome 1.1 Ability to identify and formulate Polymer Science problems using the principles of mathematics, engineering, and science.				Outcome 1.2 Ability to solve complex design problems using computing tools.				Outcome 1 Ability to identify and formulate problems using the principles of mathematics, engineering, and science.			
			Expected Class Average/	Expected Percent of students at or above average	Class Average	% Students meeting Expected Average	Expected Class Average/	Expected Percent of students at or above average	Class Average	% Students meeting Expected Average	Expected Class Average/	Expected Percent of students at or above average	Class Average	% Students meeting Expected Average
Spring 2022	Direct	10	75	70	77	70	75	70	93	100	75	70	85	90
Implementation Summary	Items implemented from previous report or after meeting previous instructor		The following techniques and technologies were included: 1. The course was taught for the first time. 2. Student worked in a group to understand polymer properties, polymer synthesis etc. Technology used: • Surface pro is used to deliver online lectures. • OneNote software gave the opportunity to write the lecture topics on white page and simultaneously share with students. • The split screen option is a game changer , it gave the privilege to share the theory and solve the problem side by side. • Individually students were assessed using exams and quizzes.				• Used active learning and collaboration tools to make the class more interactive, • Hands on 3D printing project was given to students to print 3D objects • Students did their own CAD design converted it to SLA file and then used FDM printer to print. • A detailed SOP shared with student to complete the project on 3D printing.				Students learned in detail about different 3D printing technique, competed hands-on project and learned about polymer properties and synthesis processes.			
Perceived Problems	Perceived problems are directly related to the PC and the sub items under them		• Students struggled with polymer kinetics, radical polymerization and concept of viscoelasticity • Instructor get overwhelmed with grading • Not all students were focused during the class				• Student struggles in report writing				Problems were mentioned in the sub-outcomes.			

Plans for Addressing Problems	Plans for address specific measures to address PC and their sub areas	The following is recommended for implementation. Teaching assistance is needed to support instructor.	TA is needed to support instructor. One day workshop on 3D printing will help students complete projects. Different types of printers will be helpful to learn.	Plans to address problems mentioned in the sub-outcomes
Overall Trend over Periods	Ascertain if there were improvements over previous semesters	Class average and the percentage of students reaching the expected outcome did not meet requirements.	Students' performance met the expected class average.	Students' performance met the expected class average
Were Expectations Met?	Class Average $\geq 75\%$ and $\geq 70\%$ of Students Performed at or Above Expected Average.	NO	YES	YES

**CHEG 4310 P23 ST-Polymer Science and Engineering
Spring 2022**

Title of Assignment: Exam 1

TOPICS COVERED IN Exam 1

Test 1 covered the following topics:

Concepts of molecular weight and chemical kinetics
Radical polymerization

**CHEG 4310 P23 ST-Polymer Science and Engineering
Spring 2022**

**SAMPLE TEST QUESTIONS, SOLUTION,
AND GRADING SCHEME FOR MID-TERM EXAM**

Polymer Science and Engineering CHEG 4310 PO23

Spring 2022

Exam I Time: 1Hr 20 min Date: March 9, 2022

Instructor: Dr. Nabila Shamim

Total points: 100

ABET OUTCOME

Understand and describe the structure of commercially important polymers using concepts of molecular weight and chemical kinetics

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STUDENT NAME:DATE:

Closed Book Exam NO CELL PHONE USE (PUT THEM AWAY), NO RESTROOM
BREAKS NO COLLABORATION

PROVIDE UNITS ON ALL CALCULATIONS AND ANSWERS

ANY DISHONESTY DURING THE EXAMS WILL RESULT IN “F” GRADE

WORK ALL PROBLEMS ON THE QUESTION SHEETS AND DO NOT USE ANY SHEET
OF YOUR OWN

Student Signature:

Problem 1 (20 Points) Molecular weight data for some polymer are tabulated here. Compute (a) the number-average molecular weight, (b) the weight-average molecular weight. (c) If it is known that this material's degree of polymerization is 710, which one of the polymers listed in Table 14.3 is this polymer? Why?

<i>Molecular Weight</i>		
<i>M_i g/mol</i>	<i>x_i</i>	<i>w_i</i>
22500	0.04	0.01
37500	0.07	0.04
52500	0.16	0.11
67500	0.26	0.24
82500	0.24	0.27
97500	0.12	0.16
112500	0.08	0.12
127500	0.03	0.05

$$\bar{M}_w = \sum w_i M_i \quad \bar{M}_n = \sum x_i M_i \quad m = \frac{\bar{M}_n}{DP}$$

The repeat unit molecular weights of the polymers listed in Table are as follows:

Polyethylene--28.05 g/mol

Poly(vinyl chloride)--62.49 g/mol

Polytetrafluoroethylene--100.02 g/mol

Polypropylene--42.08 g/mol

Polystyrene--104.14 g/mol

Poly(methyl methacrylate)--100.11 g/mol

Phenol-formaldehyde--133.16 g/mol

Nylon 6,6--226.32 g/mol

PET--192.16 g/mol

Polycarbonate--254.27 g/mol

Problem 2 (a) (15 Points) A polymer has a crystalline growth parameter of 2 and a rate constant of 10^{-2} s^{-2} at 100°C . The polymer is melted and then quenched to 100°C and allowed to crystallize isothermally. After 10 s, what is the percent crystallinity of the sample?

Problem 2 (b) (15 Points) i) Compute the density of totally crystalline polyethylene (C_2H_4). Polyethylene has orthorhombic unit cell also the equivalent of two ethylene repeat units contained within each unit cell:

ii) Using the answer to part (i), calculate the percent crystallinity of branched polyethylene that has density of 1.025 g/cm^3 : The density for the totally amorphous material is 0.810 g/cm^3

(Molecular weight of C is 13.08 g/mol , molecular weight of hydrogen is 1.126 g/mol ; Avogadro's number $N_A = 6.022 \times 10^{23}$ repeat units/mol, lengths in unit cell are 0.686 nm ; 0.528 nm , 0.224 nm)

Density of pure crystalline materials, $\rho = \frac{nA}{VN}$

n = number of unit cell

A = Atomic weight

V = Volume of unit cell

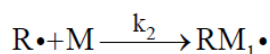
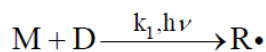
N = Avogadro's Number

Problem 3 (25 Points) It has been reported that the rate of a batch *photopolymerization* of an aqueous acrylamide solution using a light-sensitive dye is proportional to the square of the monomer concentration, $[M]^2$, and the square root of the absorbed light-intensity, $I^{1/2}$. Note that, although this polymerization is free radical, the apparent kinetics appear not to be typical of usual free-radical polymerization.

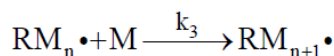
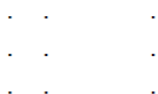
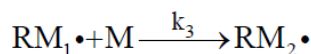
Prove the rate of polymerization is proportional to the first power of monomer concentration $[M]$ and to the square root of the initiator concentration $[I]$.

The following polymerization mechanism has been proposed to explain the observed kinetics:

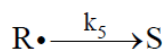
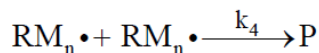
Initiation



Propagation



Termination



where

M, monomer

D, dye (which is considered as initiator I)

P, terminated polymer

S, deactivated initiator

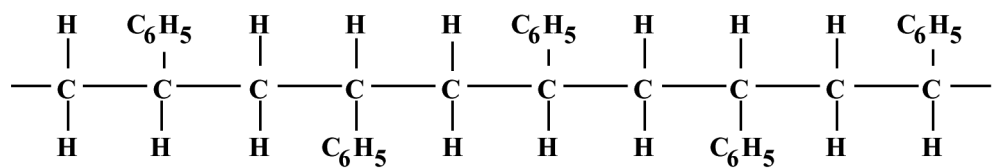
Show that this mechanism appears to be correct by deriving an equation for **the rate of propagation** in terms of $[M]$, I , and the appropriate rate constants.

The following assumptions may be made:

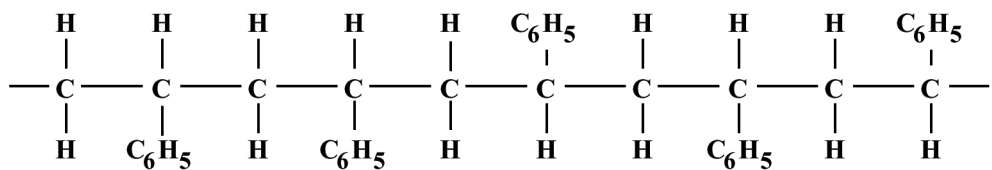
1. Equal reactivity in the propagation steps
2. Steady-state concentration of $R\cdot$ and $RM_n\cdot$
3. $k_2 \ll k_5$
4. The concentration of dye, $[D]$, that has been activated by light and thereby contributes to the first initiation step is proportional to the absorbed light intensity.

Problem 4 (25 Points) Short Questions

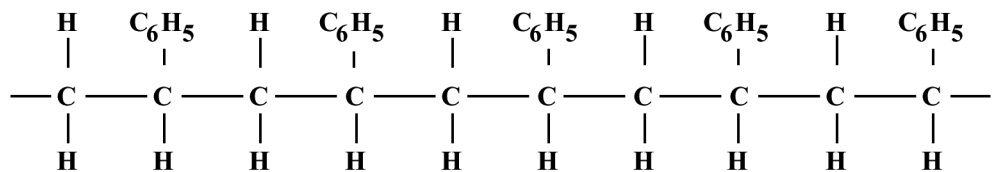
- A. **(5 Points)** Where does chain-growth polymerization usually occur?
- a) On unsaturated monomers and the reactive sites of the polymer chain
 - b) On saturated monomers and the reactive sites of the polymer chain
 - c) On two monomers
 - d) None of the above
- B. **(5 Points)** What is a benefit that thermoplastic compounds have over thermoset compounds?
- a) They have a more refined appearance
 - b) They're essentially indestructible
 - c) They can be recycled
 - d) They're higher quality
- C. **(5 Points)** Which of the following can activate chain initiation?
- a) heat
 - b) light or radiation
 - c) catalysts
 - d) all of the mentioned
- D. **(5 Points)**
- a) Compute the repeat unit molecular weight of polystyrene. Polystyrene has eight carbons and eight hydrogens
 - b) Compute the number-average molecular weight for a polystyrene for which the degree of polymerization is 25,000.
- E. **(5 Points)** Choose the name of the linear polystyrene molecule for different configurations



- a) Atactic polystyrene
- b) Syndiotactic polystyrene
- c) Isotactic polystyrene



- a) Atactic polystyrene
- b) Syndiotactic polystyrene
- c) Isotactic polystyrene



- a) Atactic polystyrene
- b) Syndiotactic polystyrene
- c) Isotactic polystyrene

Equations

$$\phi = 1 - \exp(-kt^n)$$

$$\rho = \phi(\rho_c - \rho_a) + \rho_a$$

ABOVE AVERAGE

Above Average Student Original Graded Assignment

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Polymer Science and Engineering CHEG 4310 PO23

Spring 2022

Exam I Time: 1Hr 20 min Date: March 9, 2022

Instructor: Dr. Nabila Shamim

Total points: 100

ABET OUTCOME

Understand and describe the structure of commercially important polymers using concepts of molecular weight and chemical kinetics

STUDENT NAME: Anh Nguyen DATE: 3/9/22

Closed Book Exam NO CELL PHONE USE (PUT THEM AWAY), NO RESTROOM
BREAKS NO COLLABORATION
PROVIDE UNITS ON ALL CALCULATIONS AND ANSWERS
ANY DISHONESTY DURING THE EXAMS WILL RESULT IN "F" GRADE
WORK ALL PROBLEMS ON THE QUESTION SHEETS AND DO NOT USE ANY SHEET
OF YOUR OWN

Student Signature: Anh

Problem 1 (20 Points) Molecular weight data for some polymer are tabulated here. Compute (a) the number-average molecular weight, (b) the weight-average molecular weight. (c) If it is known that this material's degree of polymerization is 710, which one of the polymers listed in Table 14.3 is this polymer? Why?

Molecular Weight M_i g/mol	x_i	w_i	$x_i M_i$	$w_i M_i$
22500	0.04	0.01	900	225
37500	0.07	0.04	2,625	1,500
52500	0.16	0.11	8,400	5,775
67500	0.26	0.24	17,550	16,200
82500	0.24	0.27	19,800	22,275
97500	0.12	0.16	11,700	15,600
112500	0.08	0.12	9,000	13,500
127500	0.03	0.05	3,825	6,375

$$\bar{M}_w = \sum w_i M_i \quad \bar{M}_n = \sum x_i M_i \quad m = \frac{\bar{M}_n}{DP}$$

The repeat unit molecular weights of the polymers listed in Table are as follows:

- Polyethylene--28.05 g/mol
- Poly(vinyl chloride)--62.49 g/mol
- Polytetrafluoroethylene--100.02 g/mol
- Polypropylene--42.08 g/mol
- Polystyrene--104.14 g/mol
- Poly(methyl methacrylate)--100.11 g/mol
- Phenol-formaldehyde--133.16 g/mol
- Nylon 6,6--226.32 g/mol
- PET--192.16 g/mol
- Polycarbonate--254.27 g/mol

$$a, \bar{M}_n = \sum x_i M_i = 73,800 \text{ g/mol}$$

$$b, \bar{M}_w = \sum w_i M_i = 81,450 \text{ g/mol}$$

$$c, m = \frac{\bar{M}_n}{DP} = \frac{73,800}{710} = 103.9 \text{ g/mol} \Rightarrow \text{polystyrene}$$

Problem 2 (a) (15 Points) A polymer has a crystalline growth parameter of 2 and a rate constant $k = 10^{-2} \text{ s}^{-2}$ at 100°C . The polymer is melted and then quenched to 100°C and allowed to crystallize isothermally. After 10 s, what is the percent crystallinity of the sample?
 $n = 2$
 $t = 10 \text{ s}$

Problem 2 (b) (15 Points) i) Compute the density of totally crystalline polyethylene (C_2H_4). Polyethylene has orthorhombic unit cell also the equivalent of two ethylene repeat units contained within each unit cell:

ii) Using the answer to part (i), calculate the percent crystallinity of branched polyethylene that has density of 1.025 g/cm^3 . The density for the totally amorphous material is 0.810 g/cm^3
 ρ_a

(Molecular weight of C is 12.01 g/mol , molecular weight of hydrogen is 1.008 g/mol ; Avogadro's number $N_A = 6.022 \times 10^{23}$ repeat units/mol, lengths in unit cell are 0.686 nm ; 0.528 nm , 0.224 nm)

$$\text{Density of pure crystalline materials, } \rho = \frac{nA}{VN}$$

n = number of unit cell

A = Atomic weight

V = Volume of unit cell

N = Avogadro's Number

$$a, \phi = 1 - \exp(-kt^n) = 1 - \exp(-10^{-2} \times 10^2) = 0.632 = 63.2\%$$

$$b, V = 0.686 \times 0.528 \times 0.224 = 0.081 \text{ nm}^3 \times \frac{1 \text{ cm}^3}{(10^7)^3 \text{ nm}^3} = 8.1 \times 10^{-23} \text{ cm}^3$$

$$\rho_s = \frac{nA}{VN} = \frac{2(12 \times 2 + 4)}{8.1 \times 10^{-23} \times 6.022 \times 10^{23}} = 1.148 \text{ g/cm}^3$$

$$\rho_s = \phi(\rho_c - \rho_a) + \rho_a$$

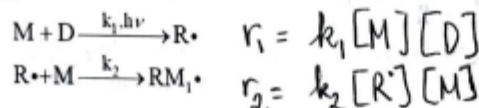
$$\Rightarrow \phi = \frac{\rho_s - \rho_a}{\rho_c - \rho_a} = \frac{1.025 - 0.810}{1.148 - 0.810} = 0.636 = 63.6\%$$

Problem 3 (25 Points) It has been reported that the rate of a batch *photopolymerization* of an aqueous acrylamide solution using a light-sensitive dye is proportional to the square of the monomer concentration, $[M]^2$, and the square root of the absorbed light-intensity, $I^{1/2}$. Note that, although this polymerization is free radical, the apparent kinetics appear not to be typical of usual free-radical polymerization.

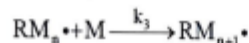
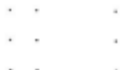
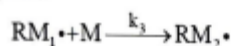
Prove the rate of polymerization is proportional to the first power of monomer concentration $[M]$ and to the square root of the initiator concentration $[I]$.

The following polymerization mechanism has been proposed to explain the observed kinetics:

Initiation

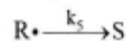


Propagation



$$r_3 = k_3 [M] [RM_n\cdot] \quad \checkmark$$

Termination



$$\begin{aligned} r_4 &= k_4 [RM_n\cdot]^2 \\ r_5 &= k_5 [R\cdot] \end{aligned}$$

where

M, monomer

D, dye (which is considered as initiator I)

P, terminated polymer

S, deactivated initiator

Show that this mechanism appears to be correct by deriving an equation for **the rate of propagation** in terms of $[M]$, I , and the appropriate rate constants.

The following assumptions may be made:

1. Equal reactivity in the propagation steps
2. Steady-state concentration of $R\cdot$ and $RM_n\cdot$
3. $k_2 \ll k_5$
4. The concentration of dye, $[D]$, that has been activated by light and thereby contributes to the first initiation step is proportional to the absorbed light intensity. $[D] \sim I$

steady state $\Rightarrow r_i = r_t$

$$[R^\cdot] \quad k_1[M][D] - k_2[R^\cdot][M] = k_5[R^\cdot] \quad k_2 \ll k_5$$

$$\Rightarrow k_1[M][D] = k_5[R^\cdot]$$

$$\Rightarrow [R^\cdot] = \frac{k_1}{k_5} [M][D]$$

$$[RM_n^\cdot] + k_2[R^\cdot][M] = k_4[RM_n^\cdot]^2$$

$$\Rightarrow [RM_n^\cdot] = \left(\frac{k_2}{k_4} [R^\cdot][M] \right)^{1/2}$$

$$= \left(\frac{k_2}{k_4} \cdot \frac{k_1}{k_5} [M]^2 [D] \right)^{1/2}$$

$$= \left(\frac{k_1 k_2}{k_4 k_5} \right)^{1/2} [M][D]^{1/2}$$

$$[D] \sim I \Rightarrow [D]^{1/2} \sim I^{1/2}$$

Rate of polymerization

$$r_3 = k_3 [M][RM_n^\cdot] = k_3 \sqrt{\frac{k_1 k_2}{k_4 k_5}} [M]^2 [D]^{1/2}$$

$$= k_3 \sqrt{\frac{k_1 k_2}{k_4 k_5}} [M]^2 I^{1/2}$$

Problem 4 (25 Points) Short Questions

A. (5 Points) Where does chain-growth polymerization usually occur?

- ☒ a) On unsaturated monomers and the reactive sites of the polymer chain
- b) On saturated monomers and the reactive sites of the polymer chain
- c) On two monomers
- d) None of the above

B. (5 Points) What is a benefit that thermoplastic compounds have over thermoset compounds?

- a) They have a more refined appearance
- b) They're essentially indestructible
- ☒ c) They can be recycled
- d) They're higher quality

C. (5 Points) Which of the following can activate chain initiation?

- a) heat
- b) light or radiation
- c) catalysts
- ☒ d) all of the mentioned

D. (5 Points)

- a) Compute the repeat unit molecular weight of polystyrene. Polystyrene has eight carbons and eight hydrogens
- b) Compute the number-average molecular weight for a polystyrene for which the degree of polymerization is 25,000.

a) $(C_8H_8)_n$ $\checkmark$ $MW = 8(12) + 8(1) = 104 \text{ g/mol}$

b) $m = \frac{\bar{M}_n}{DP}$

$\Rightarrow \bar{M}_n = m \cdot DP = 104(25,000) = 2,600,000 \text{ g/mol}$

$$\begin{array}{ccccccccccccccc} & \text{H} & & \text{C}_6\text{H}_5 & & \text{H} & & \text{H} & & \text{C}_6\text{H}_5 & & \text{H} & & \text{H} & & \text{H} & & \text{C}_6\text{H}_5 \\ & | & & | & & | & & | & & | & & | & & | & & | & & | \\ - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - \\ & | & & | & & | & & | & & | & & | & & | & & | & & | \\ & \text{H} & & \text{H} & & \text{H} & & \text{C}_6\text{H}_5 & & \text{H} & & \text{C}_6\text{H}_5 & & \text{H} & & \text{H} & & \text{H} \end{array}$$

- $$\begin{array}{cccccccccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{C}_6\text{H}_5 & \text{H} & \text{H} & \text{H} & \text{C}_6\text{H}_5 \\ | & | & | & | & | & | & | & | & | & | \\ -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C}- \\ | & | & | & | & | & | & | & | & | & | \\ \text{H} & \text{C}_6\text{H}_5 & \text{H} & \text{C}_6\text{H}_5 & \text{H} & \text{H} & \text{H} & \text{C}_6\text{H}_5 & \text{H} & \text{H} \end{array}$$

- [illegible]

- 7

AVERAGE

Average Student Original Graded Assignment

Polymer Science and Engineering CHEG 4310 PO23

Spring 2022

Exam I Time: 1Hr 20 min Date: March 9, 2022

Instructor: Dr. Nabila Shamim

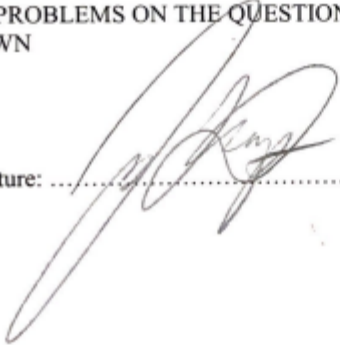
Total points: 100

ABET OUTCOME

Understand and describe the structure of commercially important polymers using concepts of molecular weight and chemical kinetics

STUDENT NAME: Jasmine Davenport DATE: March 9th, 2022

Closed Book Exam NO CELL PHONE USE (PUT THEM AWAY), NO RESTROOM
BREAKS NO COLLABORATION
PROVIDE UNITS ON ALL CALCULATIONS AND ANSWERS
ANY DISHONESTY DURING THE EXAMS WILL RESULT IN "F" GRADE
WORK ALL PROBLEMS ON THE QUESTION SHEETS AND DO NOT USE ANY SHEET
OF YOUR OWN

Student Signature: 

Problem 1 (20 Points) Molecular weight data for some polymer are tabulated here. Compute (a) the number-average molecular weight, (b) the weight-average molecular weight. (c) If it is known that this material's degree of polymerization is 710, which one of the polymers listed in Table 14.3 is this polymer? Why?

Molecular Weight M_i g/mol	x_i	w_i
22500	0.04	0.01
37500	0.07	0.04
52500	0.16	0.11
67500	0.26	0.24
82500	0.24	0.27
97500	0.12	0.16
112500	0.08	0.12
127500	0.03	0.05

a.) $\bar{m}_n = \sum x_i m_i = 73,800 \frac{g}{mol}$

b.) $\bar{m}_w = \sum w_i m_i = 81450 \frac{g}{mol}$

c.) $m = \frac{73,800 \frac{g}{mol}}{710} = 104 \frac{g}{mol}$

Polystyrene since its mass is the closest.

$$\bar{M}_w = \sum w_i M_i$$

$$\bar{M}_n = \sum x_i M_i$$

$$m = \frac{\bar{M}_n}{DP} = \frac{73,800}{710}$$

The repeat unit molecular weights of the polymers listed in Table are as follows:

- Polyethylene--28.05 g/mol
- Poly(vinyl chloride)--62.49 g/mol
- Polytetrafluoroethylene--100.02 g/mol
- Polypropylene--42.08 g/mol
- Polystyrene--104.14 g/mol
- Poly(methyl methacrylate)--100.11 g/mol
- Phenol-formaldehyde--133.16 g/mol
- Nylon 6,6--226.32 g/mol
- PET--192.16 g/mol
- Polycarbonate--254.27 g/mol

$$x_n = 0.035$$

$$V_{n+1} y_{n+1} + L_0 x_0 = V_1 y_1 + L_n x_n$$

$$L_n = \frac{(V_{n+1} y_{n+1}) - V_1 y_1}{x_n} =$$

$$L_n = 151,200$$

$$L_0 = L_n (1 - x_n) = 151,200 (1 - 0.035)$$

$$L_0 = 145,908 \text{ moles H}_2\text{O fed}$$

$$\Phi = 1 - \exp(-Kt^n) \rightarrow \Phi = 1 - \exp(-(10^{-2})(10s)^2) \quad (16.11)$$

$$\Phi = 0.6 \quad n=2 \quad K=10^{-2} s^{-2} \quad 10s \quad \rho_c=?$$

Problem 2 (a) (15 Points) A polymer has a crystalline growth parameter of 2 and a rate constant of $10^{-2} s^{-2}$ at $100^\circ C$. The polymer is melted and then quenched to $100^\circ C$ and allowed to crystallize isothermally. After 10 s, what is the percent crystallinity of the sample?

$$\% \text{ Crystallinity} = \Phi \times 100 \rightarrow 0.6 \times 100 \rightarrow \% \text{ crystallinity} = 60\%$$

Problem 2 (b) (15 Points) i) Compute the density of totally crystalline polyethylene (C_2H_4).

Polyethylene has orthorhombic unit cell also the equivalent of two ethylene repeat units contained within each unit cell:

$$\rho = \frac{(2)(30.07 \text{ g/mol})}{(0.686 \text{ nm})(0.528 \text{ nm})(0.224 \text{ nm})}$$

$$\rho = 1.27 \times 10^3 \frac{g}{nm^3} \quad n=2$$

unit mismatch
-3

ii) Using the answer to part (i), calculate the percent crystallinity of branched polyethylene that has density of $1.025 g/cm^3$. The density for the totally amorphous material is $0.810 g/cm^3$

$$\rho_c = 1.17 \frac{g}{cm^3}$$

(Molecular weight of C is $12.01 g/mol$, molecular weight of hydrogen is $1.008 g/mol$;

Avogadro's number $N_A = 6.022 \times 10^{23}$ repeat units/mol, lengths in unit cell are $0.686 nm$; $0.528 nm$; $0.224 nm$)

$$V = [(0.686)(0.528)(0.224)] nm^3$$

$$V = 0.08$$

Density of pure crystalline materials, $\rho = \frac{nA}{VN_A}$

n = number of unit cell

A = Atomic weight

V = Volume of unit cell

N_A = Avogadro's Number = 6.022×10^{23}

$$\rho_a = 0.810 \frac{g}{cm^3}$$

$$\rho = 1.025 \frac{g}{cm^3}$$

$$2C = 2(12.01 \frac{g}{mol}) \rightarrow 24.02 \frac{g}{mol}$$

$$4H = 4(1.008 \frac{g}{mol}) \rightarrow 4.032 \frac{g}{mol}$$

$$M_{C_2H_4} = (24.02 + 4.032) \frac{g}{mol}$$

$$= 28.052 \frac{g}{mol}$$

$$\rho = \Phi(\rho_c - \rho_a) + \rho_a \quad \Phi = 0.6$$

$$1.025 \frac{g}{cm^3} = 0.6(\rho_c - 0.81 \frac{g}{cm^3}) + 0.81 \frac{g}{cm^3}$$

$$.215 \frac{g}{cm^3} = 0.6(\rho_c - 0.81 \frac{g}{cm^3})$$

$$.36 \frac{g}{cm^3} = \rho_c - 0.81 \frac{g}{cm^3}$$

$$\rho_c = 1.17 \frac{g}{cm^3}$$

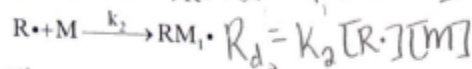
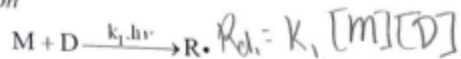
$$\frac{6.36}{4.82 \times 10^{22}}$$

Problem 3 (25 Points) It has been reported that the rate of a batch *photopolymerization* of an aqueous acrylamide solution using a light-sensitive dye is proportional to the square of the monomer concentration, $[M]^2$, and the square root of the absorbed light-intensity, $I^{1/2}$. Note that, although this polymerization is free radical, the apparent kinetics appear not to be typical of usual free-radical polymerization.

Prove the rate of polymerization is proportional to the first power of monomer concentration $[M]$ and to the square root of the initiator concentration $[I]$.

The following polymerization mechanism has been proposed to explain the observed kinetics:

Initiation



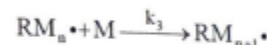
Propagation



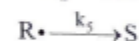
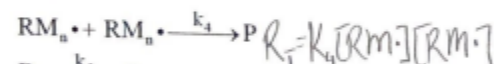
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Termination



where

M, monomer

D, dye (which is considered as initiator I)

P, terminated polymer

S, deactivated initiator

Show that this mechanism appears to be correct by deriving an equation for the **rate of propagation** in terms of $[M]$, I , and the appropriate rate constants.

The following assumptions may be made:

1. Equal reactivity in the propagation steps
2. Steady-state concentration of $R\cdot$ and $RM_n\cdot$
3. $k_2 \ll k_5$
4. The concentration of dye, $[D]$, that has been activated by light and thereby contributes to the first initiation step is proportional to the absorbed light intensity.

-15-
 Prove $R_p = k_3 [M]^2 [I]^{1/2}$

Problem 4 (25 Points) Short Questions

- A. (5 Points) Where does chain-growth polymerization usually occur?
- ☒ a) On unsaturated monomers and the reactive sites of the polymer chain
 - ☐ b) On saturated monomers and the reactive sites of the polymer chain
 - ☐ c) On two monomers
 - ☐ d) None of the above

- B. (5 Points) What is a benefit that thermoplastic compounds have over thermoset compounds?

- ☐ a) They have a more refined appearance
- ☐ b) They're essentially indestructible
- ☒ c) They can be recycled
- ☐ d) They're higher quality

- C. (5 Points) Which of the following can activate chain initiation?

- ☐ a) heat
- ☐ b) light or radiation
- ☐ c) catalysts
- ☒ d) all of the mentioned

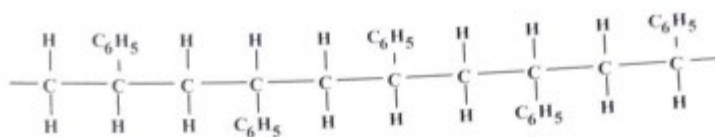
D. (5 Points)

- a) Compute the repeat unit molecular weight of polystyrene. Polystyrene has eight carbons and eight hydrogens $8C = 8(12.08 \frac{g}{mol}) \rightarrow 96.64$ $8H = 8(1.01 \frac{g}{mol}) \rightarrow 8.08$ $96.64 + 8.08 = 104.72 \frac{g}{mol}$
- b) Compute the number-average molecular weight for a polystyrene for which the degree of polymerization is 25,000.

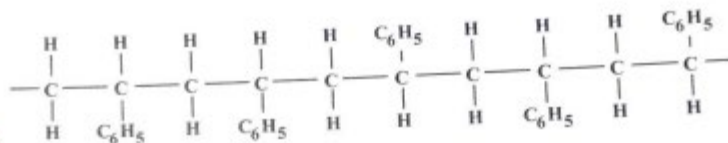
a.) Polystyrene = $104.72 \frac{g}{mol}$

b.) $\bar{M}_n = m(DP) \rightarrow (104.72 \frac{g}{mol})(25,000) \quad \boxed{\bar{M}_n = 2.62 \times 10^6 \frac{g}{mol}}$

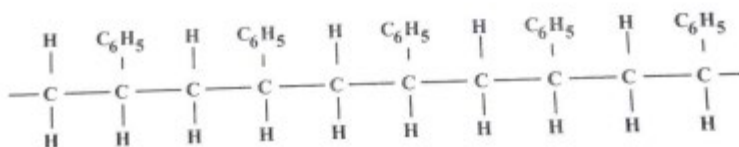
E. (5 Points) Choose the name of the linear polystyrene molecule for different configurations



- ☒ b) Syndiotactic polystyrene



- ☒ a) Atactic polystyrene
- ☐ b) Syndiotactic polystyrene
- ☐ c) Isotactic polystyrene



- a) Atactic polystyrene
b) Syndiotactic polystyrene
c) Isotactic polystyrene

BELOW AVERAGE

Below Average Student Original Graded Assignment

Polymer Science and Engineering CHEG 4310 PO23

Spring 2022

Exam I Time: 1Hr 20 min Date: March 9, 2022
Instructor: Dr. Nabila Shamim
Total points: 100

ABET OUTCOME

Understand and describe the structure of commercially important polymers using concepts of molecular weight and chemical kinetics

STUDENT NAME: Chinenye Ihe DATE: 03/9/2022

Closed Book Exam NO CELL PHONE USE (PUT THEM AWAY), NO RESTROOM
BREAKS NO COLLABORATION
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WORK ALL PROBLEMS ON THE QUESTION SHEETS AND DO NOT USE ANY SHEET
OF YOUR OWN

Student Signature: 

Problem 1 (20 Points) Molecular weight data for some polymer are tabulated here. Compute (a) the number-average molecular weight, (b) the weight-average molecular weight. (c) If it is known that this material's degree of polymerization is 710, which one of the polymers listed in Table 14.3 is this polymer? Why?

Molecular Weight M_i g/mol	x_i	w_i
22500	0.04	0.01
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52500	0.16	0.11
67500	0.26	0.24
82500	0.24	0.27
97500	0.12	0.16
112500	0.08	0.12
127500	0.03	0.05

Find:

- M_n
- M_w

a) $w_i M_i$:

$$22500(0.01) + 37500(0.04) + 52500(0.11) + 67500(0.24) + 82500(0.27) + 97500(0.16) + 112500(0.12) + 127500(0.05)$$

$$\bar{M}_w = 81,450$$

b) $x_i M_i$:

$$22500(0.04) + 37500(0.07) + 52500(0.16) + 67500(0.26) + 82500(0.24) + 97500(0.12) + 112500(0.08) + 127500(0.03)$$

$$\bar{M}_n = 73,800$$

$$\bar{M}_w = \sum w_i M_i$$

$$\bar{M}_n = \sum x_i M_i$$

$$m = \frac{\bar{M}_n}{DP}$$

The repeat unit molecular weights of the polymers listed in Table are as follows:

- Polyethylene--28.05 g/mol
- Poly(vinyl chloride)--62.49 g/mol
- Polytetrafluoroethylene--100.02 g/mol
- Polypropylene--42.08 g/mol
- Polystyrene--104.14 g/mol
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- Phenol-formaldehyde--133.16 g/mol
- Nylon 6,6--226.32 g/mol
- PET--192.16 g/mol
- Polycarbonate--254.27 g/mol

$$c) m = \frac{\bar{M}_n}{DP}$$

$$= \frac{73,800}{710}$$

$$m = 103.9 \sim 104$$

* Polystyrene is the polymer being talked about, b/c its molecular weight is close to that of the calculated "m".

$$n = 2$$

$$t = 10^3$$

$$k = 10^{-2} s^{-2}$$

Problem 2 (a) (15 Points) A polymer has a crystalline growth parameter of 2 and a rate constant of $10^{-2} s^{-2}$ at $100^\circ C$. The polymer is melted and then quenched to $100^\circ C$ and allowed to crystallize isothermally. After 10 s, what is the percent crystallinity of the sample?

Problem 2 (b) (15 Points) i) Compute the density of totally crystalline polyethylene (C_2H_4). Polyethylene has orthorhombic unit cell also the equivalent of two ethylene repeat units contained within each unit cell:

ii) Using the answer to part (i), calculate the percent crystallinity of branched polyethylene that has density of $1.025 g/cm^3$. The density for the totally amorphous material is $0.810 g/cm^3$.

(Molecular weight of C is $13.08 g/mol$, molecular weight of hydrogen is $1.126 g/mol$; Avogadro's number $N_A = 6.022 \times 10^{23}$ repeat units/mol, lengths in unit cell are $0.686 nm$; $0.528 nm$, $0.224 nm$)

$$V = L \times W \times H$$

$$V = 0.0811$$

Density of pure crystalline materials, $\rho = \frac{nA}{VN}$

$$\phi = 1 - \exp(-kt^n)$$

$$\rho = \phi(\rho_c - \rho_a) + \rho_a$$

$$13.08(2) =$$

$$26.16$$

$$1.126(4) =$$

$$4.504$$

$$A = 30.664$$

n = number of unit cell

A = Atomic weight

V = Volume of unit cell

N = Avogadro's Number

a) after 10s,

$$\phi = 1 - \exp(-kt^n)$$

$$= 1 - \exp(-10^{-2} s^{-2} (10 s)^2)$$

$$= 1 - \exp(-1)$$

$$= 0.632$$

b) $\rho = \frac{nA}{VN}$

$$= \frac{2(30.664)}{(0.0811)(6.022 \times 10^{23})} = 1.26 \times 10^{-21} \text{ unit?}$$

$$\phi = 1.26 \times 10^{-21} (0.810 - 1.025) + 1.025$$

$$= 1.03$$

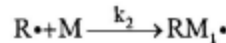
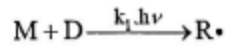
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Problem 3 (25 Points) It has been reported that the rate of a batch *photopolymerization* of an aqueous acrylamide solution using a light-sensitive dye is proportional to the square of the monomer concentration, $[M]^2$, and the square root of the absorbed light-intensity, $I^{1/2}$. Note that, although this polymerization is free radical, the apparent kinetics appear not to be typical of usual free-radical polymerization.

Prove the rate of polymerization is proportional to the first power of monomer concentration $[M]$ and to the square root of the initiator concentration $[I]$.

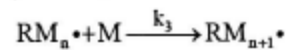
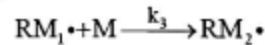
The following polymerization mechanism has been proposed to explain the observed kinetics:

Initiation

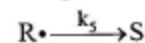


$$R = k_1 h\nu + MD$$

Propagation



Termination



25

where

M, monomer

D, dye (which is considered as initiator I)

P, terminated polymer

S, deactivated initiator

Show that this mechanism appears to be correct by deriving an equation for the **rate of propagation** in terms of $[M]$, I , and the appropriate rate constants.

The following assumptions may be made:

1. Equal reactivity in the propagation steps
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3. $k_2 \ll k_3$
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Problem 4 (25 Points) Short Questions

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B. (5 Points) What is a benefit that thermoplastic compounds have over thermoset compounds?

- ☐ a) They have a more refined appearance
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C. (5 Points) Which of the following can activate chain initiation?

- ☐ a) heat
- ☒ b) light or radiation
- ☐ c) catalysts
- ☐ d) all of the mentioned

D. (5 Points)

- a) Compute the repeat unit molecular weight of polystyrene. Polystyrene has eight carbons and eight hydrogens
- b) Compute the number-average molecular weight for a polystyrene for which the degree of polymerization is 25,000.

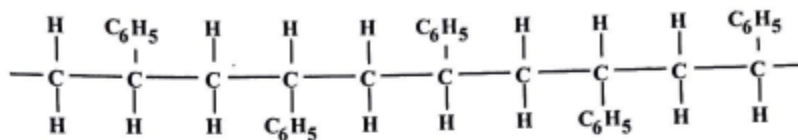
$$C = 12$$

$$H = 1$$

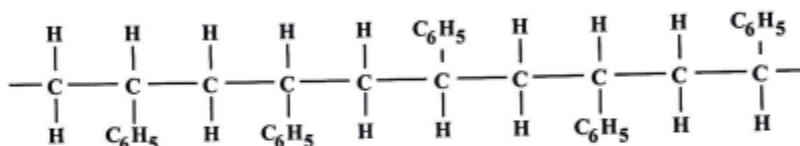
$$\begin{aligned} a) M_w &= \sum w_i M_i \\ &= 12(8) + 1(8) \\ &= \boxed{104} \end{aligned}$$

$$\begin{aligned} b) M_n &= \sum x_i M_i \\ &= \frac{25000}{104} = \boxed{240} \end{aligned}$$

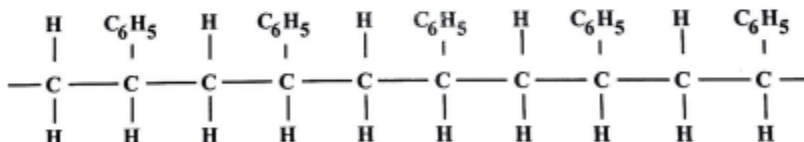
E. (5 Points) Choose the name of the linear polystyrene molecule for different configurations



- a) Atactic polystyrene
- ☒ b) Syndiotactic polystyrene
- c) Isotactic polystyrene



- ☒ a) Atactic polystyrene
- b) Syndiotactic polystyrene
- c) Isotactic polystyrene



- a) Atactic polystyrene
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- ☒ c) Isotactic polystyrene

**CHEG 4310 P23 ST-Polymer Science and Engineering
Spring 2022**

Quiz 4

TOPICS COVERED IN Quiz 4

- 1. Viscoelasticity**

**CHEG 4310 P23 ST-Polymer Science and Engineering
Spring 2022**

**Quiz #4 QUESTIONS, SOLUTION,
AND GRADING SCHEME**

Date: Monday April 18, 2022

CHEG 4310
Quiz 4 on Viscoelasticity

Problem 1: (8 Points) Explain the Maxwell Spring-Dashpot Model for linear viscoelastic response. Derive the mathematical expression of Maxwell model.

Problem 2: (6 Points) In a stress relaxation test a constant strain ϵ_0 acts as the input to the material, Draw a schematic expression of the time dependent stress.

Problem 3 (6 points)
Explain Creep, Stress Relaxation and Voigt-Kevin Model of Viscoelasticity

ABOVE AVERAGE

Above Average Student Original Graded Assignment

Date: Monday April 18, 2022

CHEG 4310

Quiz 4 on Viscoelasticity

Problem 1: (8 Points) Explain the Maxwell Spring-Dashpot Model for linear viscoelastic response. Derive the mathematical expression of Maxwell model.

The system includes a spring and a dashpot connected in series.



$$\text{stress } \tau = \tau_{\text{spring}} = \tau_{\text{dashpot}}$$

$$\text{strain } \gamma = \gamma_{\text{spring}} + \gamma_{\text{dashpot}}$$

$$\text{- stress relaxation: } \tau = \tau_0 e^{(-E/\eta)t}$$

$$\text{- creep: } J(t) = \frac{\gamma(t)}{\tau_0} = \frac{1}{E} + \frac{t}{\eta}$$

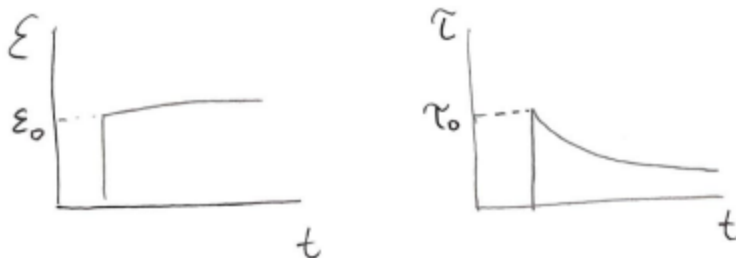
$$\tau_{\text{spring}} = E \gamma_{\text{spring}}$$

$$\tau_{\text{dashpot}} = \eta \dot{\gamma}_{\text{dashpot}}$$

$$\text{Stress relaxation modulus} \\ E(t) = \frac{\tau(t)}{\gamma_0} = \frac{\tau_0 e^{(-E/\eta)t}}{\gamma_0} = E_0 e^{(-E/\eta)t}$$

$$\begin{aligned} \text{spring: solid property (elastic)} &\rightarrow \gamma(t) = \frac{\tau_0}{\eta} t + \frac{\tau_0}{E} \\ \text{dashpot: liquid property (viscous)} &= \frac{\tau_0}{\eta} t + \gamma_0 \end{aligned}$$

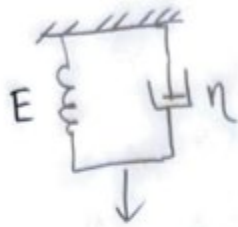
Problem 2: (6 Points) In a stress relaxation test a constant strain on ϵ_0 acts as the input to the material. Draw a schematic expression of the time dependent stress.



Problem 3 (6 points)

a. Explain Creep, Stress Relaxation and Voigt-Kevin Model of Viscoelasticity

- Creep: when stress is held constant, strain is increasing
- stress relaxation: when strain is held constant, stress is decreasing
- Voigt-Kevin Model is a spring and a dashpot is connected in parallel



$$\text{stress } \tau = \tau_{\text{spring}} + \tau_{\text{dashpot}}$$

$$\text{strain } \gamma = \gamma_{\text{spring}} + \gamma_{\text{dashpot}}$$

AVERAGE

Average Student Original Graded Assignment

Date: Monday April 18, 2022

CHEG 4310

Quiz 4 on Viscoelasticity

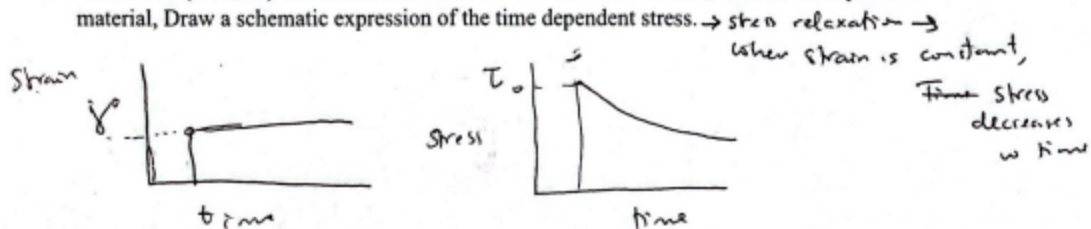
Tharun
Aragundade.

Problem 1: (8 Points) Explain the Maxwell Spring-Dashpot Model for linear viscoelastic response. Derive the mathematical expression of Maxwell model.


 Dashpot absorbs energy
 Spring stores energy
 $\gamma = \gamma_{\text{spring}} + \gamma_{\text{dashpot}}$
 $\tau = \tau_{\text{spring}} = \tau_{\text{dashpot}}$
 $\gamma_{\text{spring}} = \frac{\tau}{G}$ $\gamma_{\text{dashpot}} = \frac{\tau}{\eta}$
 $\tau = \tau_0 \exp\left(-\frac{G}{\eta} t\right)$
 $\tau = \tau_0 \exp\left(-\frac{t}{\lambda}\right)$
 $\gamma(t) = \frac{\tau_0 t}{\eta} + \frac{\gamma_0}{1}$

η = viscous modulus
 G = elastic modulus
 $\lambda = \frac{\eta}{G}$ → relaxation time
 τ_0 = time

Problem 2: (6 Points) In a stress relaxation test a constant strain on ϵ_0 acts as the input to the material, Draw a schematic expression of the time dependent stress.



Problem 3 (6 points)

a. Explain Creep, Stress Relaxation and Voigt-Kevin Model of Viscoelasticity

Creep → when the stress is constant, strain increases with time

$\gamma(t)$
 Creep Compliance → $J(t) = \frac{t}{\eta} + \frac{\gamma_0}{\tau_0}$

Stress relaxation → Stress decreases with time when there's constant strain is constant.

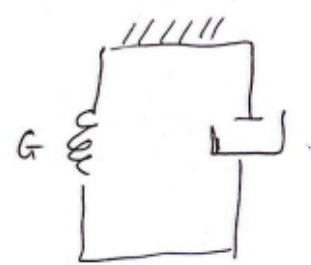
Relaxation modulus = $G \exp\left(-\frac{t}{\lambda}\right)$ → ~~Creep compliance~~ ~~$\tau_0 \exp$~~

Voigt-Kevin model = $\gamma_{\text{spring}} = \gamma_{\text{dashpot}}$ & $\tau = \tau_{\text{spring}} + \tau_{\text{dashpot}}$

Scanned with CamScanner

CONTD
 Vortg't Kevin make = $\gamma(t) = \frac{\bar{I}_0}{G} (1 - e^{-\frac{t}{\tau}})$

$$\gamma(t) = \frac{\gamma(t)}{\bar{I}_0} = \frac{1}{G} (1 - e^{-\frac{t}{\tau}})$$



BELOW AVERAGE

Below Average Student Original Graded Assignment

Separation Process: Quiz 1

Date: January 31, 2022

1. Water evaporating from a pond does so as if it were diffusing across an air film 0.50 cm thick. The diffusion coefficient of water in 20°C air is about 0.25 cm²/s. If the atmospheric air is 50% saturated, answer the following questions:

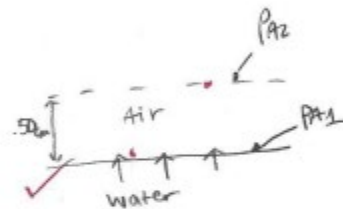
- Draw a schematic diagram of the mass transfer process. 2 Points
 - Calculate the molar flux of evaporating water across the air film. Consider equimolar diffusion. 5 Points
 - How fast will the water level drop in a day? 3 Points
- Given vapor pressure of water at 20°C is 17.54 mmHg

$$N_A = -D_{AB} \frac{dC_A}{dz} + \frac{C_A}{C_T} (N_A + N_B)$$

Total Concentration

$$N_A = -\frac{D_{AB}}{RT} \frac{dp_A}{dz} + \frac{p_A}{P} (N_A + N_B)$$

Total Pressure



given:

(water) $D_{AB} @ 20^\circ\text{C} = 0.25 \text{ cm}^2/\text{s} = 2.5 \times 10^{-5} \text{ m}^2/\text{s}$

Vapor pressure water @ 20°C = 17.54 mmHg

$= \frac{17.54 \text{ mmHg}}{760 \text{ mmHg}}$

$= 0.0230789474 \text{ atm}$

Air = 50% saturated

$T = 20^\circ\text{C} + 273 = 293 \text{ K}$

Thickness = $\frac{0.50 \text{ cm}}{1} \cdot \frac{3 \text{ m}}{100 \text{ cm}} = 5.3 \times 10^{-3} \text{ m}$

$M_{H_2O} = 18.02 \text{ g/mol}$

1 day = 24 hr = 86400 seconds

We know:

$R = 82.06 \times 10^{-3} \text{ atm} \cdot \text{m}^3/\text{kmol} \cdot \text{K}$

1 atm = 760 mmHg

$\frac{0.25 \text{ cm}^2}{1} \cdot \frac{1 \text{ m}^2}{(100 \text{ cm})^2} = 2.5 \times 10^{-5} \text{ m}^2$

$N_A = -2.5 \times 10^{-5} \text{ m}^2 \left[\frac{0.0230789474}{5.3 \times 10^{-3} \text{ m}} + \right]$

**CHEG 4310 P23 ST-Polymer Science and Engineering
Spring 2022**

Final Project

TOPICS COVERED IN Project 1

- 1. Use of Fused Deposition Modeling (FDM) to print 3D printed objects**

**CHEG 4310 P23 ST-Polymer Science and Engineering
Spring 2022**

**Final Project # QUESTIONS, SOLUTION,
AND GRADING SCHEME**

Final Project
CHEG 4310 P23 ST-Polymer Science and Engineering
Spring 2022

Hello Students

We have learned about basic information on 3D printing and had a demonstration class on 3D printing.

Students will use Flash Forge Guider II 3D printer in this project. This activity aims to familiarize the students with the steps of the rapid prototyping process and software.

First, choose a model from online repository websites such as TinkerCAD, which have existing 3D model files in STL file format. Then students are required to download the file, copy it in an USB and bring it to CL Wilson for printing.

You may need to scale the model, adjust position and orientation, and finally follow instructions to 3D print the selected file using a Fused Deposition Modeling (FDM) printer.

Please sign in to confirm your printing schedule. Please be reminded we have one 3D printer and 5 groups will be using it. Therefore, team work and spirit is highly encouraged.

How to write a report for the final project report

Maximum 5 -7 pages, 1 in margin all around, use 12 font times new roman or Arial font. Cover page is not included in the page limit.

1. **Abstract:** A brief, comprehensive summary of the contents of the report. Specific, clear, active, and deliberative writing, Includes the top 4-6 important concepts, findings, or implications. The abstract should give an overview of the background leading to the aims or objectives. The materials and methods, results and conclusion. (Abstract should be 200 words).

2. **Background/ Literature Review:** Give background information on 3D printing.

3. **Objectives/ Aims:**

2. **Materials and Methods:** Describe the materials and printing methods of Flash Forge

under methods you can have the following items

a. **Design:** The design you obtained from tinkerCAD. Give the actual image of the design, dimensions, how you have scaled it, show the design in the workplane, and download it STL file.

b. **Table :** Prepare a table that summarizes the parameters of the print with values

Parameters

Layer Height

Infill pattern

Infill Density

Exterior shells

Raft

Angle

Extruder temperature

Plate temperature.

Print time

If you find have more parameters include them.

3. **Challenges:** what problems you have faced in the printing process, including all the images.

4. **Results and Discussion:** How does the final product look like. What was done to improve/overcome the challenges?

5. **Future Work:** What are your plan and thoughts about 3D printing

6. **Conclusions:** Write a short paragraph on what you have learned and how the knowledge and hands-on experience of 3D printing will benefit you.

7. **References.**

ABOVE AVERAGE

Above Average Student Original Graded Assignment



CHEG 4310 – P23

Polymer Science and Engineering

Final Project on 3D Printing

Due Date: May 6, 2022

Submitted by: Timothy Waugh
Erron Williams

Submitted to: Dr. Shamim

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Abstract

Since the Emergence of 3D printing in the early 1980's multiple different printing process have been developed and patented. For this project we used the Flash Forge Guider II, a printer that creates designs by melting and cooling our provided filament, polylactic acid (PLA) in a process known as Fused Deposition Modeling (FDM). Using Tinkercad design software, we were able to adjust and optimize our design in order to complete our objective of recreating the PVAMU marching band logo known as the Marching Storm. In this report you will find our design size parameters as displayed in Tinkercad as well as the parameters measured for us automatically by the Guide II print software. In order to create a comprehensive analysis of the results we printed two models, one with fully automated supports and then a second print with selected supports underneath the logo. In the challenges section, we discuss the obstacles we faced while designing our model replica as well as attempting to carve our model out of the encasing supports. In our final sections we elaborate on ideas on how we can apply the concepts learned from this project in the future and a conclusion of the report overall.

Background

In 1981 Hideo Kodama of Japan was able to create a process form 3D printing. This process utilized UV light for polymerization of the resin which is now known as stereolithography (SLA). Later in 1986 Charles Hull would submit for the first patent for SLA. He then went on to start his own company and release the first commercial 3D printer. Selective Laser Sintering (SLS) would later become a patented process by a man named Carl Deckard in 1988. SLS uses powdered materials to film models using a laser. Fused Deposition Modeling (FDM) became patented by Scott Crump. This method is unique in that it does not require special light to form models as the filament is simply heated through a nozzle and then called on a platform. Due to this advantage FDM is now the most common form of 3D-Printing.

Objectives/Aims

The objective of this 3D printing project was to creatively design an item that was related to Prairie View A&M University and print it using a 3D printer. Our aim was to do something specific to the university like the panther or the PVNSBE emblem, and something a bit more complicated than our first design of a present box. We decided to print the logo for the PVAMU Marching Storm, which is the marching band at Prairie View A&M University.

Materials and Methods

The Flash Forge Guider II is a 3D printer that uses the Fused Filament Fabrication (FFF) also known as Fused Deposition Modeling (FDM) to create 3-dimensional models based off of computer-aided design CAD. Our group used Tinkercad for our design as it was a simple

software that was also easily accessible since it's web based. For our designs we used polylactic acid (PLA) for the material, an easy to print and environmentally safe material. In order to print the Guider II must heat the filament to extrude it onto the platform in which it begins to form the model layer by layer.

-a. Design

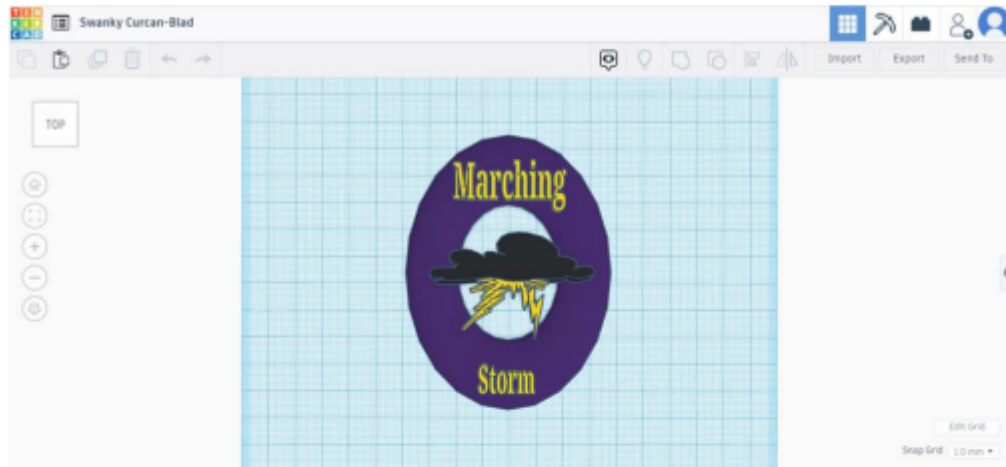


Figure 1. Tinkercad Design of PVAMU Marching Storm Logo

The design created using Tinkercad was the PVAMU Marching Storm logo. There were two designs of the Marching Storm logo as the second design's only difference from the first was that the hole in the circle was much wider making the cloud in the middle too big since we wanted the cloud to touch parts of the circle. The Tinkercad design was much bigger than the design in FlashForge Guider II as the X plane was 75.00 mm, Y plane was 100.00 mm, and the Z plane was 5.00 mm. The Tinkercad design was later scaled down to approximately 40.00 mm by 53.00 mm by 5.00 mm in FlashForge. Two samples were printed.

-b. Table

Table 1. Parameters of First and Second Designs

Parameters	Value (2 nd Design)
Layer Height	0.18 mm
First Layer Height	0.27 mm
Infill Pattern	Hexagon
Infill Density	15%

Exterior Shells	2
Raft	Enable
Angle	0.0°
Exterior Temperature	220 °C
Plate Temperature	50 °C (45 °C)
Print Time	39 minutes (38 minutes)
Print Speed	60 mm/s
Travel Speed	80 mm/s
Estimated Material (Filament Length)	2.33 m (2.30 m)
Number of Layers	57 layers

This table lists the value of the parameters associated with the print of both designs. The values for the second design are in parenthesis. The lesser number of supports contribute to the second design having a slightly less print time and estimated material.

Challenges



Figure 2. 1st Attempt at Removing Supports



Figure 3. 2nd Attempt at Removing Supports

One of the initial challenges we had was that Tinkercad had a very limited number of designs we could do for a design specific to Prairie View A&M University. Most of our ideas were denied like a band member playing the trumpet or the PVNSBE emblem because there was nothing in Tinkercad that mirrored the wanted designs. Another challenge was making the words on our design visible since the 3D printer prints only in white as the words were blending in with the supports. So, we had to find the right thickness to make the words visible, but it's still not

completely clear. We used auto supports in our first design, which covered most of the design. This caused a problem near the lightning bolt areas as the supports were nearly impossible to remove. The amount of supports likely made the supports very hard to take off as the figures above show the attempt to take off the supports using a knife.

Results and Discussions



Figure 4. 1st Design with Full Supports



Figure 5. 1st Design with no Supports

These images are of the first design with full supports on and with as much as possible, a design with all supports broken off. The cloud is almost embedded in the supports, which contributed to the difficulty of removing the supports and leaving a stringy like appearance near the lightning bolts. For the second design, we worked to improve the lightning bolt section of the design.



Figure 6. 2nd Design with Full Supports



Figure 7. 2nd Design with no Supports

We believed the first design was good except for the lightning bolt section, and it appeared that an excessive number of supports hindered that area. For this reason, we opted to remove all supports except for the outsides of the bottom of the circle. This not only helped clear up the lightning bolt area of the design, but it helped make it much easier to take the supports off. The lack of supports seemed to have weakened the toughness of the supports making it easier to

break. This is visible by how hollow the circle is behind the cloud as opposed to the first design. There is noticeable improvement, even in the design with full supports as the lightning bolts have a less stringy appearance, but it is undeniably clear in the next figure once the supports were broken.

Future Work

The opportunities with 3D-printing are vast. For chemical engineering there are plenty of jobs that specialize in materials where 3d-printing knowledge can come in handy. At Adidas the company often has employees use a 3D printer to create small models of sneaker designs to display of meeting in early stages of production. The new “Adidas 4D” line consist of running sneakers, all of which the midsoles were created by a 3D printer. There has been a steady increase in investments in at home 3D printers, typically FDM however there are YouTube Vloggers that use SLS and SLA models to create content for their channels. To our surprise this is more financially feasible then most would thin as there are many affordable options for 3D printers on Amazon and Best buy that range around \$250-\$400.

Conclusions

The objective of printing the PVAMU Marching Storm logo was completed, but we believe the design could have been more refined. The design could have been smoother, and a third print could have been taken with possibly zero supports to be able to compare all designs better. Seeing how recent the advancements of this field have been, it would be interesting to see how the advancement of future 3D printers will help users avoid the challenges we faced during this project. If time permits, it may also be beneficial for future student who take this course to possibly become familiar with AutoCad in order to create more accurate design quality. Overall, this project was knowledgeable, hands on, and fun as it gave valuable experience that can be taken in the real world.

References

Flashforgeguiderii3dprinter userguide - B&H photo. www.Flashforge.com. (n.d.). Retrieved May 4, 2022, from https://www.bhphotovideo.com/lit_files/484155.pdf

When was 3D printing invented? the history of 3D printing -. BCN3D Technologies. (2021, December 10). Retrieved May 4, 2022, from <https://www.bcn3d.com/the-history-of-3d-printing-when-was-3d-printing-invented/>

AVERAGE

Average Student Original Graded Assignment

Roy G. Perry
College of Engineering
Submitted to Dr. Shamim



Final Project on 3D Printing

Submitted By:
Alessia Williams
Garred Essissima

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Introduction

3D printing involves the layer-by-layer creation of three dimensional physical structures from a computer aided design (CAD) software (Shahrubudin 2019). The successive construction of the objects categorizes 3D printing as a form of additive manufacturing. Although it is a novel technology, 3D printing has experienced leaps in technological advancement since it was first commercialized in 1980 (Shahrubudin 2019). The naturally flexible technology expanded to include more printing methods and materials of construction increasing the allowance for customization and application. ASTM International, a non-profit organization that establishes global technical process standards, defines 7 distinct categories of 3D printing: Binder jetting, Directed energy deposition, Material extrusion, Materials jetting, Powder bed fusion, sheet lamination, and Vat Photopolymerization (Shahrubudin 2019).

All of these printing methods have their unique advantages. Binder jetting is capable of printing large objects. Directed energy deposition is especially useful for repairs or additions to existing structures. Materials jetting allows for smooth finishes and compatibility with majority materials. Powder bed fusion is functionally quick and highly accurate. Sheet lamination is appealing because it can do full color prints and the material is easily handled and recycled. Vat Photopolymerization method is advantageous for premium detailed products. Lastly, material extrusion is appealing for its low cost and the wide use of the method (Shahrubudin 2019).

Being widely used and low cost, material extrusion is the ideal printing method for instructional programs, such as CHEG 4310 Polymer Science, that aim to introduce 3D printing to educate students on the science and application of polymers. Despite being a small subsection of the polymer industry, the vast applications of 3D printers and the manipulated polymers speaks volumes to the possibility, flexibility, and adaptability of polymers and polymer technology as a whole. The specific material extrusion process used for this project is Fused Deposition Modeling (FDM) where thermoplastic (in this case polylactic acid (PLA) filament is heated, extruded and deposited in layers by the Flash Forge Guider II 3D printer. The printing design was developed and uploaded using tinkerCAD. Completing this project is similar to professionals 3D printing prototypes. The object is cheap, rough, and on a smaller scale than the actual object would be.

Objectives

The aim for this project was to utilize the knowledge gained from 3D printing Laboratory Session One in order to more efficiently produce a complex 3D object that represents PV. Particularly, our mission was to apply our learned knowledge of the necessity and function of supports for 3D printing complex shapes. In addition, having gained first hand experience comprehending the material strength of solid printed PLA vs PLS supports, we aimed to more effectively and precisely separate the supports while keeping the desired structure completely intact.

Materials and Methods

The height of our finished print came out to be 1.9 inches, the width came out to be 1.3 inches, and finally the depth of the finished print is 0.84 inches. Our layer height ended up being 235 consecutive layers of PLA filament. Our 3D print design took a total of 54 minutes to print, which is a feasible time based on the intricacy of the design, and the fact that we had a time constraint to finish our 3D printed design. We understand that we had to choose a design that represented Prairie View A&M. Our first thought was to represent Prairie View by printing a football helmet, but this design was not recommended because other students choose the same design. We continued to brainstorm and found that a Prairie View cheerleader was great in representing our school. We designed our 3D print by finding our base model of the cheerleader and adding pom poms to her hand, and finally Putting the letters, "PV" to represent that this is a Prairie View cheerleader.

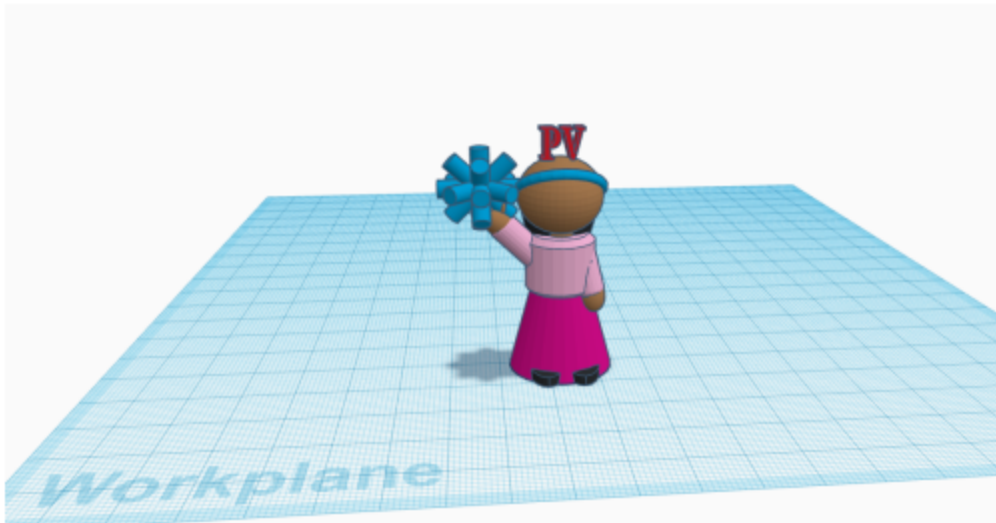


Figure 1. TinkerCAD Design

Table 1. Design and Print Parameters

Parameters	Values
Layer Height	0.18 mm
Infill Pattern	Hexagon
Infill Density	15%
Exterior Shells	2
Raft	Yes
Angle	55° Overhang Threshold
Extruder Temperature	220° C
Plate Temperature	30° C



Figure 2. 3D Print with Supports

Results and Discussion



Figure 3. Front 3D Print



Figure 4. Back 3D Print

Our resulting print was a successful print with a few minor defects. When our 3D print was finished we made sure we documented our design and print parameters and we removed our print from the printing plate. The Prairie View cheerleader needed support to print successfully because of the area in our design where there was greater than a 45° angle, if this was not added the print will not have enough support to build upon. We carefully removed these supports with sharp tools to remove the surrounding support from our cheerleader design. In the process of removing these supports, the "V" in our design was slightly damaged. Lastly we then needed to remove the raft in which the print first began, from our cheerleader.

Challenges

The first challenge encountered when attempting to print our PV Cheerleader design was schedule time conflict. The print was intended to be completed last Friday April 29th; however, unfortunately another team had taken that time slot on the sign up sheet before we could. Not wanting to wait until the last project week to print, my teammate and I attempted to rush and complete the printing Thursday evening before the office closed at 5pm. A detrimental mistake we made was heating up the platform along with the extrusion unit, despite knowing that PLA needed a cool surface to properly hold and print. The Flash Forge Guider II took a very long time to cool and seemed to stall above the ideal platform temperature of 30 degrees preventing us from completing a print that day. Despite this inconvenience, we rescheduled our project print to the next earliest available time, Monday May 2nd at 10am. Understanding the procedures for machine preheating and filament load we were able to effectively print our PV Cheerleader design the second time around.

The second challenge experienced during this project was the separation of the PLA supports from the desired PV Cheerleader shape. This challenge was expected and prepared for by strategically selecting the proper tool for extraction. The tool had to be tough, to not bend at the force, movement or angle required for effective PLA support removal. In addition, the tool needed to be easy to handle and have a sharp end for precise application. In the end, we settled on a stainless steel pick that was a part of a skin extraction kit one of us happened to own. While the tool was ideal for the task, the PV letters on top of the Cheerleader's head proved too delicate to cleanly separate the supports around them. The force applied to remove the supports around the lettering ended up removing the "V" from its designed place.



Figure 5. Stainless Steel Pick From Extraction Kit

Future Work

The next step for us would be to focus more on the design aspect of 3D printing and strengthen our command of the tinkerCAD software. There are two sides of the 3D printing process, the physical print - which we have familiarized ourselves with during this experiment - and the software design - where the product customization is nearly limitless. Improving upon our proficiency of tinkerCAD would allow us to further explore the creative freedom this process allows and possibly produce even more unique complicated designs than the PV Cheerleader.

Conclusion

To conclude with our 3D printing project we were asked to choose a design that represented Prairie View A&M, download our design, give specifications of the design and to add complex parts to our design. We chose our design of a Prairie View cheerleader and our complex parts of our design was the pom poms added to cheerleader hands, and the "PV" letters on top of our design. We faced many challenges along this process like schedule conflict, plate temperature and the removal of our supports from our design. We were able to talk amongst each other as team members, find a solution and successfully print our 3D printed Prairie View cheerleader.

References

- Shahrubudin, N, et al. "An Overview on 3D Printing Technology: Technological, Materials, and Applications ." *2nd International Conference on Sustainable Materials Processing and Manufacturing (SMPM 2019)*, vol. 35, 2019, pp. 1–4.

BELOW AVERAGE

Below Average Student Original Graded Assignment

Prairie View A&M University
Roy G. Perry College of Engineering
Department: Chemical Engineering



CHEG 4310 - P23

Polymer Science and Engineering
Project name: Final 3-D Printing

Lab Completed: May 3, 2022

Submitted by
Ibrahim Arogundade
Chinenye Ihe

Submitted to
Dr. Nabila Shamim

Abstract

This project is aimed at generating a desired design using the process of additive manufacturing. The details of the process will be documented in this report. The design is a PVAMU logo which is represented by the individual letters in the logo. The image will be designed in AutoCAD which will later be imported into the flash forge application on the computer connected to the 3D printer in the laboratory. The design dimensions will be set to the desired dimensions that will be chosen. All the settings associated with the design parameters will also be set to a suitable one. The printing process was filled with challenges that were associated with the design, especially the shape and thickness of the design. The challenges affected the design, but a resulting 3D design was still generated. The 3D design was a PVAMU logo as desired however it was lacking the required thickness due to the challenges faced.

Background

3D printing or otherwise known as additive manufacturing is a process whereby layers of material are being deposited and joined together to generate a three-dimensional object, this process is controlled by a computer. Ever since its inception, additive manufacturing has found a way in every industry. It has proven advantageous, and it has increased productivity in several industries. It is commonly used in the aeronautics industry in their research department to make jet engines, it is also utilized in the medical industries to develop replacements of bones, tissues, and ligaments for patients. All these advantages, however, come with disadvantages. Additive manufacturing is becoming widespread and readily available to the common people. It can be used to easily develop weapons which can be left unchecked and used to harm people.

Methods of 3D printing

There are several methods of additive manufacturing, listed below. The method that will be selected for a printing process is dependent on five criteria's which are: budget, mechanical requirements, physical appearance, geometry, and material type.

POLYMER 3D PRINTING METHOD

- Stereolithography (SLA)
- Selective Laser Sintering (SLS)- Power bed fusion
- Fused Deposition Modeling (FDM)- Material Extrusion
- Digital Light Process (DLP)
- Multi Jet Fusion (MJF)
- PolyJet

METAL 3D PRINTING METHOD

- Direct Metal Laser Sintering (DMLS)- Power bed fusion
- Electron Beam Melting (EBM)- Power bed fusion

Fused Deposition Modeling (FDM)- Material Extrusion

The printing method that will be used in this project will be FDM (Fused deposited Modeling). FDM is a 3D printing technology process that utilizes material extrusion. Material extrusion is a process whereby the material is being heated, drawn through a nozzle and each layer is being deposited upon the other layer. The nozzle can move horizontally and vertically depending on the design. This process is very advantageous, it is inexpensive, user friendly and operates at a low temperature compared to the other printing methods. However, it can be disadvantageous as the materials that are used in the process can be toxic, it is susceptible to warping and it needs support. The materials that can be used for the FDM process are PLA, ABS, PET, PETG, TPU, Nylon, ASA, PC, HIPS and Carbon Fiber.

Figure 1: FDM printing technology parts

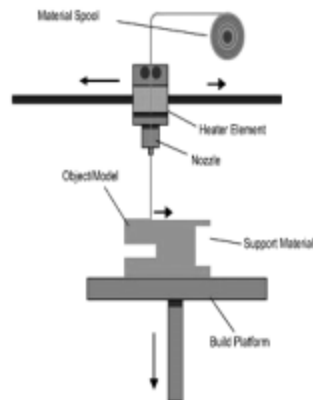
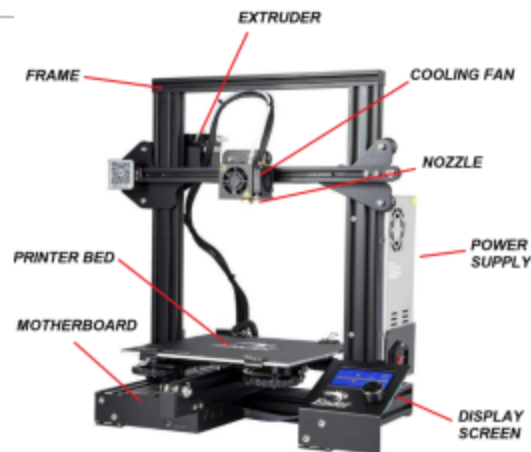


Figure 2: FDM printing technology parts (2)



Objective

The objective was to design and generate a 3D printed structure of the PVAMU logo with its individual letters representing the overall image.



Figure 3: Preliminary Picture of the design

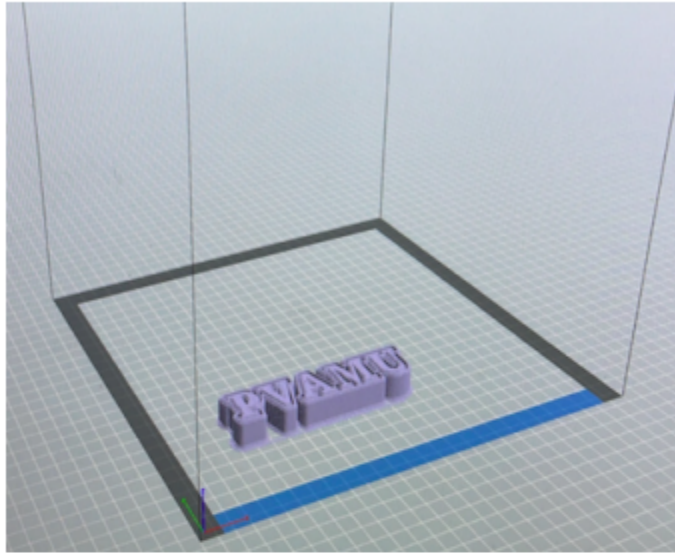


Figure 4: Resulting AutoCAD design

Methods:

- a. The printing method that was utilized was the FDM- material extrusion method which was carried out using a Flash Forge printer. The process for 3D printing can be summarized in three steps: picking and downloading the 3D model, slicing, and exporting the model and then building it. For this project we picked our model, as seen in Figure 1, from tinkercad and then uploaded it onto the printer's computer through the flash forge app. After uploading it to the app you set the dimensions (X: 117.38mm, Y:22.77mm, Z:15.60mm) to your preferred model and then select the print option to print it. The time will then be generated. The time for this project was 2 hours 13 minutes. The printing material used was PLA.

- b. *Table 1:* Parameters of the print

Parameters	Values
Layer Height	0.18mm
First Layer Height	0.27mm
Infill Pattern	Hexagon
Infill Density	15%
Supports	Enable
Top Solid Layers	3
Bottom Solid Layers	3
Exterior shells	2

Raft	Enabled
Resolution	Standard; Wall
Extruder Temperature	225oC
Platform Temperature	105oC
Print speed	60mm/s
Travel speed	80mm/s
Material type	ABS
Filament Length	9.49 meters
Material Density	1.04g/cm3
Estimated Weight	23.74g
Set Dimensions:	
X	117.38mm
Y	22.77mm
Z	15.60mm

Challenges

Some challenges that can arise when using the flash forge printer are that the extruder/ nozzles can clog, the filament not sticking to the print bed, stringing, warping, rings and waves, flared base, layer shifting, failed bridges, and layer separations. The extruder clogging can cause thin layers, holes, or cracks in our model. When the filament does not stick to the print bed it causes the model to end up a jumble mess. Stringing would have your model coming out with strands of fly-away filament. Warping is when the filament plastic cools and becomes smaller. Warped models are uneven and can lift off the print bed entirely. Rings and waves would have the exterior of the model with a distinctive pattern of rings or waves. Having a flared base would have the first few layers becoming squished and flaring out wider than intended. Layer shifting is a big problem because it means there is usually a mechanical failure, the model ends up with a slight lean. Failed bridges happen when there are no supports, the bridge may sag, crack or be stringy. Layer separation are cracks between layers where the filament has not properly adhered to the previous layer (Charlotte, 2018). For our model, the filament was not sticking to the print bed, we also had stringing, warping and layer shifting. To avoid or fix these issues, these are our suggestions: use a heated build plate, ensuring that the build plate is leveled correctly, use of brim, raft and decrease the use of excessive cooling.

Results

The resulting printed object was a PVAMU logo with its individual letters, however we were not able to achieve the desired thickness that was shown on the original AutoCAD design. The challenges we faced modified the result so that the printed design will be leaner and thinner than expected.

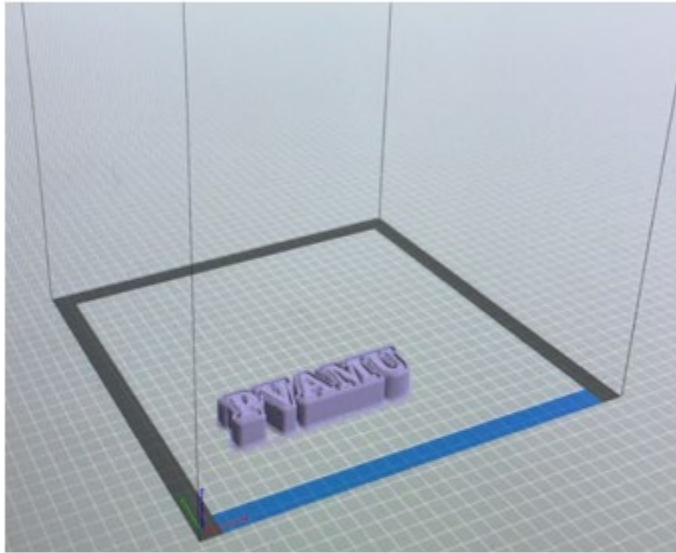


Figure 5: AutoCAD design



Figure 6: Resulting printed Image

Future Work

Additive manufacturing is a process that is not common among people unless they are actively involved in the industry that is being utilized. 3D printing is an extremely useful tool that should be available in schools and public libraries for public use. I plan to use 3D printing in the future for some works or designs. I think it will be useful in creating materials that will be useful and used for leisure activities. Some of the processes also seem unbelievably cheap with regards to the manufacturing process.

Conclusions

This project opened our eyes to the challenges faced when care is not taken in 3D printing. We now must investigate ways to avoid such challenges and prevent them from occurring later. We expected the result to be successful and the print job to be quite simple but were dissatisfied with the results and the challenges that arose. If we were to take on the project again, we would be mindful to prepare and ensure our settings and temperatures are conducive for the success of the project.

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