

*Determining the strength and durability of polymer in relation to physical properties based on differing polymer chain length through destructive testing*

**Abstract:**

Polymers are an important classification of matter that include materials such as DNA and styrofoam. Polymers in the world could be improved by being made to withstand greater physical damage. This experiment was conducted to determine whether the lengths of polymer chains due to different amounts of initiators and catalyst used when creating the polymers would affect the polymers' resistance to physical damage. Seven types of polymers were created in the lab with different ratios of catalyst:initiator. The polymers were poured into rod molds and disk molds and tested for strength using suspended weights and sudden concentrated impact. However, it was found that there was too much uncertainty, both in the creation of the polymers and the subsequent testing, to definitively draw a conclusion about the polymer that was most effective at withstanding damage. These results hold little significance because of the uncertainty, and would require a re-test to accurately answer the experimental question.

**Introduction:**

The purpose of this lab was to determine which catalyst:initiator ratio used to make the polymers would allow the polymer to be more resistant to physical damage.

A *monomer* ("mono-" meaning one, "-mer" meaning part) is a single molecule that may chemically bond with other molecules to form a *polymer* ("poly-" meaning many). A polymer is a long molecule formed by the combination of many repeating molecular units (monomers). Polymers can occur naturally, like cotton and proteins, or be manufactured synthetically like styrofoam. Chain-growth polymerization is a process in which monomers link one at a time to an initiator, which is the substance that begins the chemical reaction. The amount of initiator introduced to the monomer determines the chain length of the polymer. When less initiator is added, there are fewer chains; thus the number of monomers in each chain will be greater. When more initiator is introduced, the number of chains increases and the number of monomers in each chain decreases. The greater the chain length, the stronger the polymer. When the chains become longer, it allows for more points of interaction between the individual polymer chains. It is more difficult to separate the polymer chains when there are many points of interaction between the molecules. Polymers become *cross-linked* when a chemical reaction causes the individual polymer chains to link to one another. Cross-linking strengthens the intermolecular bonds between polymer chains, making the polymer more durable. The *catalyst* is the substance added to the initiator and monomer that lowers the amount of energy required to begin the reaction. This allows the reaction to happen more quickly and at a lower temperature. The amount of catalyst within the solution has no direct impact on the chemical structure of the polymer.

Polymers are bonded covalently, meaning the atoms within the molecules attract each other's electrons, causing the atoms to "stick" together. The molecules then covalently bond to each other, forming a chain of monomers. While still a type of covalent bond, the attraction between the molecules is much weaker than the attraction between the atoms within the molecules, causing the polymer to have a low melting point and relatively low durability, as less energy is required to separate the molecules due to the weak intermolecular forces.

**Methods:**

*Appropriate safety precautions must be taken in the lab. This lab involved the use of hazardous chemicals. If ingested or inhaled, these chemicals could cause serious physical damage. All experiment work using*

*these chemicals was conducted in the fume hoods. Aprons and safety goggles were worn at all times, and rubber gloves were worn when handling chemicals.*

#### Creating the Polymers:

Using 85 mL of Caprolactone as the monomer, seven types of polymers were created in the lab with different amounts of initiator (1-Octanol) and catalyst (Stannous Octoate) to alter the length of the polymer chains. Polymer A (75:1:1) was made with 1.53 mL of 1-Octanol and 3.19 mL of Stannous Octoate; Polymer B (100:1:1) was made with 1.15 mL of 1-Octanol and 2.39 mL of Stannous Octoate; Polymer C (200:1:1) was made with 0.57 mL of 1-Octanol and 1.12 mL of Stannous Octoate; Polymer D (400:1:1) was made with 0.29 mL of 1-Octanol and 0.60 mL of Stannous Octoate; Polymer E (600:1:1) was made with 0.19 mL of 1-Octanol and 0.340 mL of Stannous Octoate; Polymer F (800:1:1) was made with 0.14 mL of 1-Octanol and 0.30 mL of Stannous Octoate; Polymer G (1000:1:1) was made with 0.12 mL of 1-Octanol and 0.24 mL of Stannous Octoate. The chemicals were in a liquid state when combined, and, in order for the chemical reaction to take place that would allow the mixture to become viscous enough to be poured into the polymer molds, the mixture needed to be agitated and heated to the point that the catalyst would allow the initiators to begin forming chains of monomers. This was achieved by combining the chemicals in a 250 mL Erlenmeyer flask and placing the flask on a magnetic stir/hot plate. This agitated and heated the mixture in such a way that it allowed for the polymer chains to form, making the mixture more viscous.

#### Testing the Polymers:

The polymer rods were tested for relative strength when acting as an anchor for suspended weights. First, one of the rods was placed between two tables. Weights were then suspended from the rod incrementally until the rod fractured and broke. This test was repeated for each type of polymer (A-F) that was created in the lab.

The disks were tested for resistance to damage when exposed to sudden, concentrated force. A hammer was attached to the floor via hinge. The disk was placed on the floor, and the hammer was then dropped on the puck from increasingly severe angles (15 degree increments) until the disk broke. This angle was then recorded. The procedure was repeated for all types of polymer disks (A-F) that were created in the lab.

#### **Results:**

Polymers A, B, D, and E were tested during Test One. Polymer A was found to be able to suspend 600 grams on average; Polymer B suspended an average of 800 grams; Polymer D suspended an average of 1032 grams; Polymer E suspended an average of 932 grams.

Polymers A, B, C, D, E, F, and G were tested during Test Two. Polymer A fractured at an average drop angle of 15 degrees; Polymer B fractured at an average drop angle of 35 degrees; Polymer C fractured at an average drop angle of 45 degrees; Polymer D fractured at an average drop angle of 50 degrees; Polymer E fractured at an average drop angle of 22.5 degrees; Polymer F fractured at an average drop angle of 22.5 degrees; Polymer G fractured at an average drop angle of 45 degrees.

Table 1: Polymer ratio type A, B, D, and E and corresponding average weight required to break polymer rods

Polymer Type	Average Breaking Point (grams)
A	600
B	800
D	1032
E	932

Table 2: Polymer ratio type A-G and corresponding degree measurement of average drop angle required to damage polymer disk

Polymer Type	Average angle degree from drop
A	15
B	35
C	45
D	50
E	22.5
F	22.5
G	45

Figure 1: Recorded average suspension strength of polymers A, B, D, and E

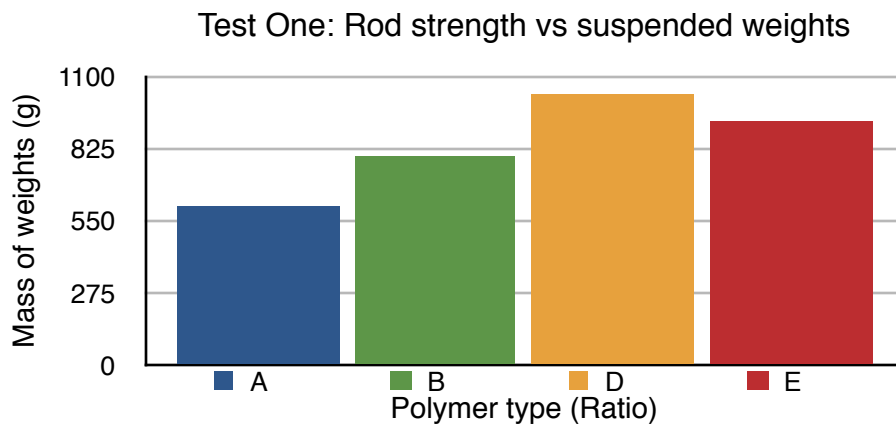
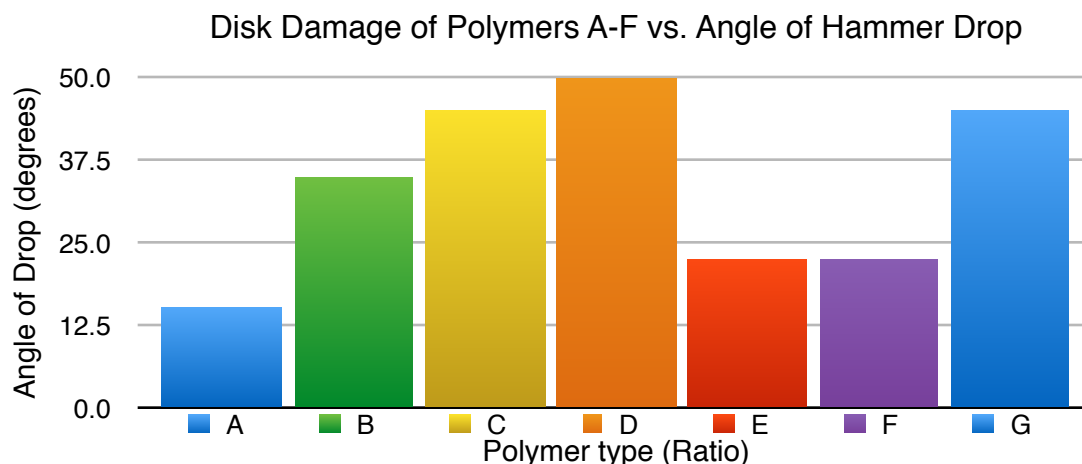


Figure 2: Recorded average hammer drop angle required to damage polymer disks A-G



### Discussion:

The purpose of this lab was to determine which ratio of catalyst: initiator would be most effective in creating a polymer that would be resistant to physical damage. Two tests were conducted (one on the polymer rods, one on the polymer disks) to examine the strength of the polymer rods and disks.

In relation to Test One that was examining the suspension strength of polymer rods A, B, D, and E, it appears the first three polymers (A, B, D) support the idea that a smaller amount of initiator will result in longer polymer chains and will increase the strength of the polymer (Figure 1). However, Polymer E supported 100 fewer grams than Polymer D (Table 1), which is inconsistent with the length of polymer chains vs. strength. I am not confident in the findings of Test One. As our time in the lab was cut short, the polymers were poured into the molds before they may have been ready, resulting in improper curing of the polymers, which could result in flaws in the final polymers. Not only this, but I was not present during the time when the tests were conducted, so I am unsure whether the tests were conducted consistently and whether the recorded data was accurate. As only four types of the polymer rods were deemed acceptable enough to test, I believe there is not enough data to accurately determine whether there was a trend in polymer chain length and corresponding strength. In this case, due to the significant gaps of data (polymers C, F, and G), I would say that the individual data points are more important than the data trend when drawing conclusions about the results of this test.

The data for Test Two, testing the impact damage resistance of polymer disks, illustrates approximately no correlation between the polymer chain length and the amount of force the polymer disks were able to withstand. Polymers A-D show an increase in force required to break the disk (Figure 2), but the data for Polymers E-G does not follow the trend line. The angle required to break Polymers E and F was exactly half of the angle required to break Polymer D (Table 2). This data is inconsistent with the relationship between the length of the polymer chains and its durability. As with Test One, I am not confident in the results of this test for a variety of reasons. Improper curing due to rushed mold preparation in the lab could account for some of the discrepancy in the data. There were also several different groups crafting polymers using the same ratio, so it's highly likely that each polymer varied slightly in the amounts of chemicals used. This variation could result in slightly longer or shorter polymer chains, which would alter the polymer's resistance to damage. I was not present during the testing of the polymer disks, and, as a result, must rely on secondhand information when displaying my results. There is no way for me to be certain of the accuracy of the collected data, so I cannot be certain that my results are indeed correct. Assuming the results are in fact accurate, there still exists an area of uncertainty. With some types of the polymers, there was only one disk that was acceptable to test, whereas other types had multiple disks. Thus, there were inconsistent amounts of data that could skew the results. For instance,

Polymers A and G were only tested once, whereas Polymer D was tested six times. As a result, the data for Polymer D has a more accurate average than the data for Polymers A and G.

Based upon the data and the amount of uncertainty around the creation and testing, I cannot definitively say whether the chain length of the polymers as determined by the ratio of catalyst: initiator is effective at creating polymers that can withstand greater amounts of physical damage.