

Near-Net Shape Reusable Masking Material for Application in Hip Stem Coatings

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Abstract

DePuy Synthes was in need of a better method with which to mask their hip stems during the coating process. Currently, they use masking tape which is a time intensive and non-reusable solution. Our project examined 5 potential polymers (PVC, Nylon 6/6, PTFE, TPE, UHMWPE) for use as near-net shape reusable masking materials. PVC was eliminated as a potential material due to its solubility and warping in acetone. The results show that Nylon 6/6, PTFE, TPE, and UHMWPE, which showed no significant degradation to both 100 cycles and 4 weeks of exposure to acetone and toluene, are suitable for use as reusable masking materials. Therefore, cost and ease of manufacturing were used as the determining criteria. Although UHMWPE was slightly cheaper than Nylon 6/6, it can only be produced by compression molding which poses difficulties in producing near-net shape intricately designed hip-stem masks. Therefore, we have selected Nylon 6/6 as the best potential masking material due to its low cost and ability to be injection molded.

This work is sponsored by DePuy Synthes Joint Reconstruction in Warsaw, IN



Project Background



Figure 1: DePuy Synthes Summit tapered hip stem line, with no coating, or various amounts of porous coating.

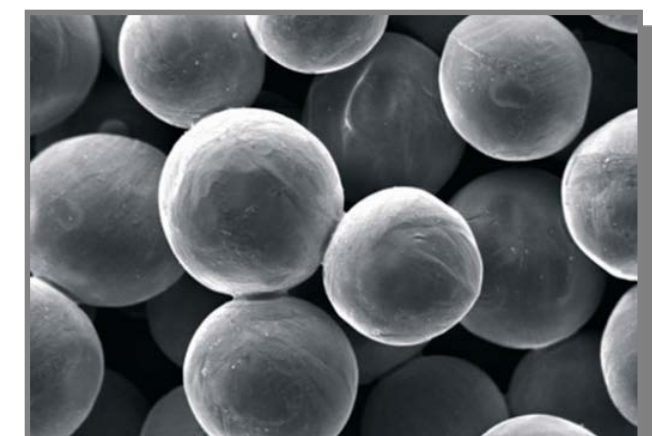


Figure 2: SEM image of porous titanium coating known as Porocoat.

Figures 1 and 2 show DePuy tapered hip stems and the titanium based porous coating applied to the scratch-fit regions. When spraying porous coatings on their hip joint reconstruction stems, DePuy Synthes currently uses masking tape to cover the non-coated regions of the stem in the coating process. This process is inefficient and time intensive, causing large delays in the coating process. Therefore, DePuy has asked our team to come up with a re-usable masking material that can be used to mask the un-coated portions of the hip stems. This masking material must be able to withstand cyclic soaking in acetone and toluene, be low profile, and cost less than \$5/part.

Experimental Procedure

Potential Masking Materials:

- Five polymers were selected: PVC, UHMWPE, TPE, Nylon 6/6, and PTFE
- TPE sheet had a thickness of 1/8 inch while the other polymers had a thickness of 1/16 inch
- Sectioned UHMWPE, PTFE, TPE, Nylon 6/6 into tensile bars (ASTM D638)
- The polymers were sectioned into tensile bars using a band saw machine and a laser cutter

Chemical Degradation Experiments:

1) Preliminary Soaking Experiment

- Soak 1 inch by 3 inch samples in acetone and toluene for 48 hours

2) Long Soak Experiment

- Soak the tensile bars in acetone and toluene for 2 and 4 weeks

3) Interval Soaking Experiment

- Soak the tensile bars in acetone and toluene for 20, 40, 60, 80, and 100 cycles
- Each cycle consists of soaking the bars in the chemicals for 15 minutes, and air/furnace dry them for 15 minutes

- Mimic industrial use of the potential masks

Characterization Techniques:

1) Optical Microscopy

2) Tensile Testing

- ASTM D638 Standard Tensile Procedure

3) FTIR

- Standard Absorbance Pattern

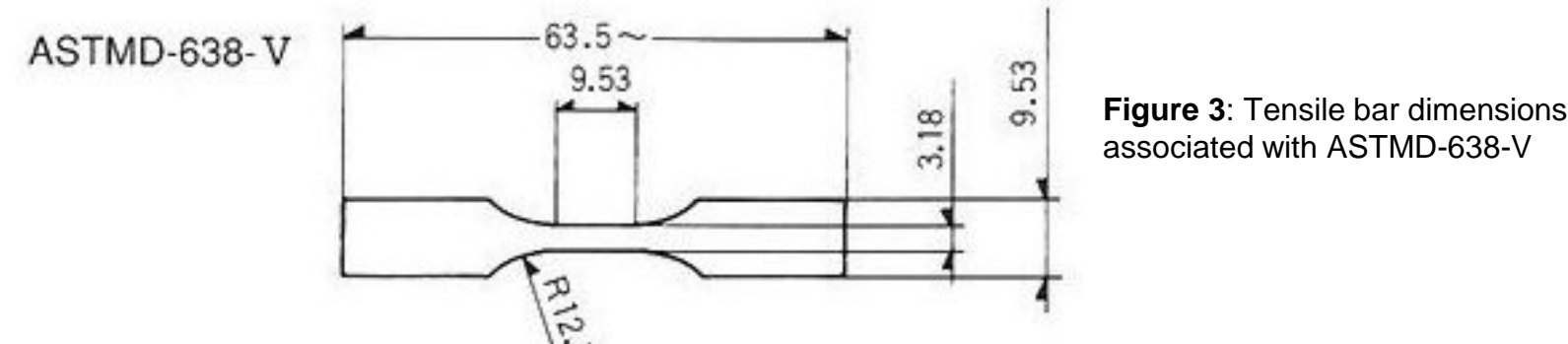


Figure 3: Tensile bar dimensions associated with ASTM D638-V

Results and Discussion



Figure 4: Warpage of PVC in acetone.

The preliminary soaking experiment was our initial attempt to cause degradation to each of the five polymers. After soaking in acetone and toluene for 48 hours, 4 out of the 5 polymers remained unchanged. PVC warped severely from soaking in acetone as is shown in Figure 4. When selecting materials, PVC was selected because it is used in a variety of corrosion-resistant applications. On further research, we found that PVC is actually soluble in acetone and therefore would not be a good polymer for our application. Since the preliminary soaking experiment provided no evidence to eliminate the other 4 polymers, we decided to try two longer soaking experiments with two different methodologies and analyze the results using optical microscopy, tensile testing, and FTIR.

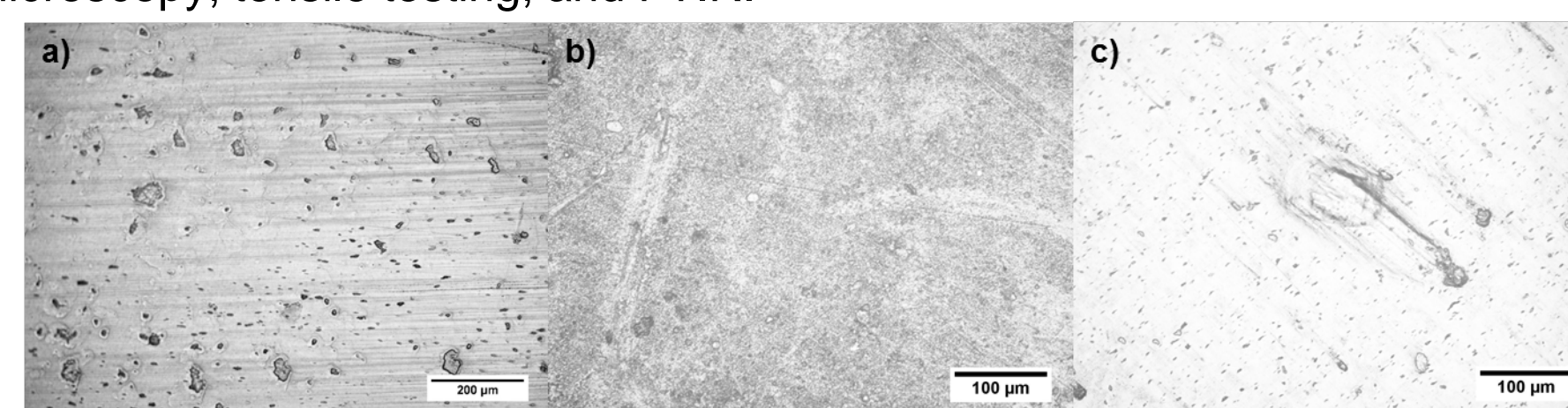


Figure 5: Interval soaking of Nylon after a) 0, b) 40, c) 100 cycles in acetone.

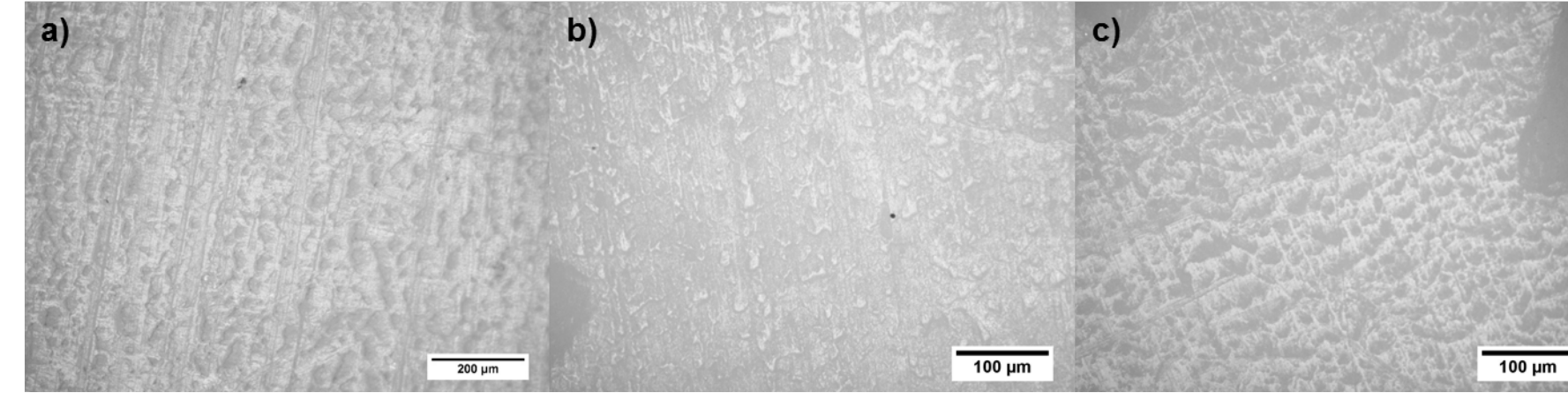


Figure 6: Interval soaking of PTFE after a) 0, b) 40, and c) 100 cycles in acetone.

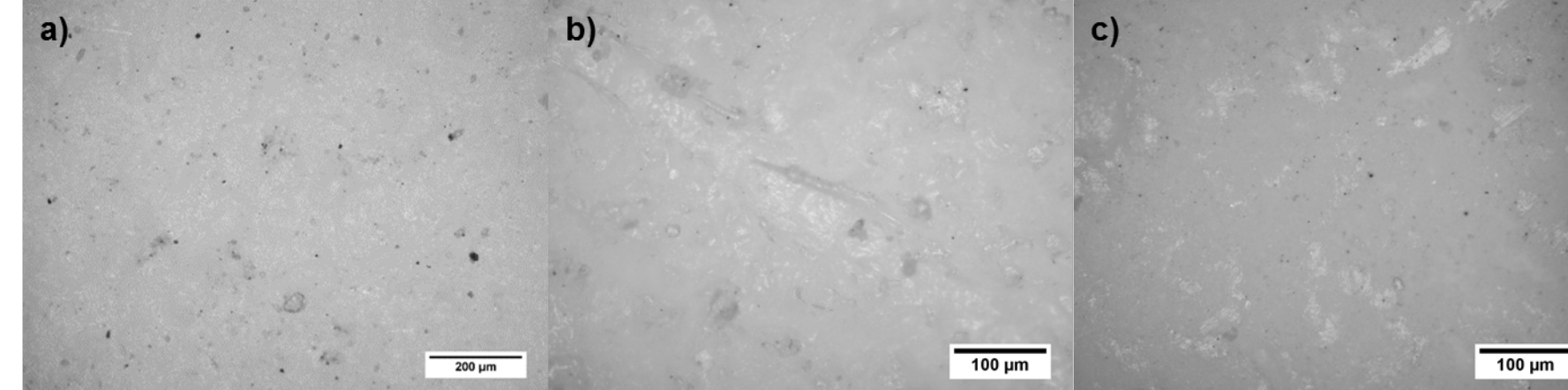


Figure 7: Interval soaking of TPE after a) 0, b) 40, and c) 100 cycles in acetone.

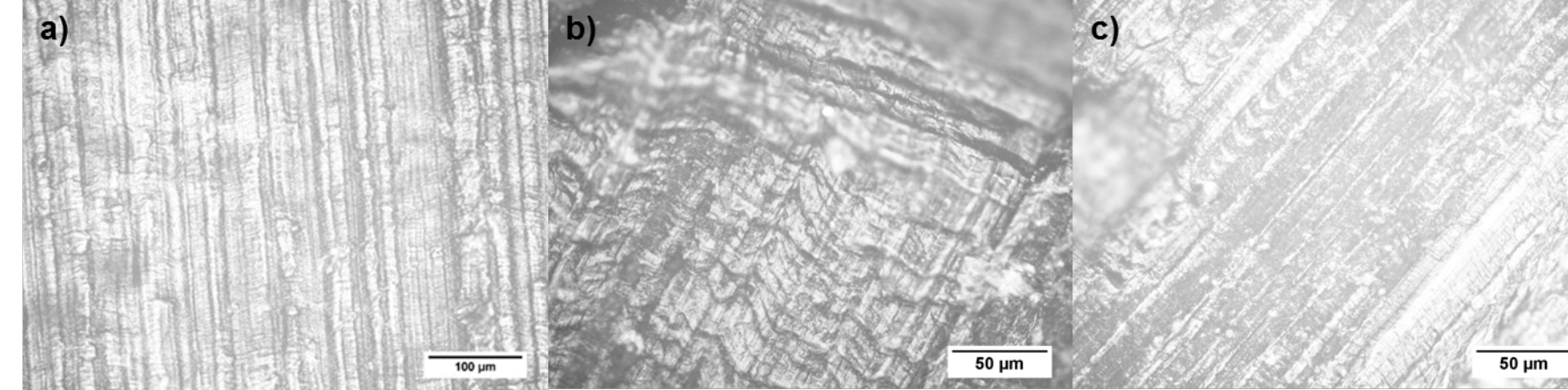


Figure 8: Interval soaking of UHMWPE after a) 0, b) 40, and c) 100 cycles in acetone.

Figures 5, 6, 7, and 8 show the results of interval soaking after 0, 40, and 100 cycles of soaking in acetone. These images show that little to no change occurred to the structure of the surface of the polymer after 100 cycles of soaking in acetone. In analyzing the images of samples soaked for 2 and 4 weeks in acetone and toluene as well as the samples that were cycle soaked in toluene, little to no change in structure could be observed. Therefore, we were unable to definitively use optical images as evidence that any of the 4 remaining polymers degraded as a result of soaking. Since optical microscopy yielded no concrete evidence, we decided to determine if there was any significant change in tensile strength as a result of soaking.

Table 1: Yield Stress data for Nylon samples obtained through uniaxial tensile testing.

Nylon						
Long Soak (Acetone)	Average Yield Stress (MPa)	Long Soak (Toluene)	Average Yield Stress (MPa)	Cycle Soaking (Acetone)	Average Yield Stress (MPa)	Cycle Soaking (Toluene)
Unsoaked	55.17	Unsoaked	55.17	Unsoaked	55.17	Unsoaked
2 Weeks	57.15	2 Weeks	56.10	20	54.73	20
4 Weeks	49.50	4 Weeks	58.50	40	58.57	40
				60	50.50	60
				80	60.00	80
				100	60.70	100

Table 2: Yield Stress data for PTFE samples obtained through uniaxial tensile testing.

PTFE						
Long Soak (Acetone)	Average Yield Stress (MPa)	Long Soak (Toluene)	Average Yield Stress (MPa)	Cycle Soaking (Acetone)	Average Yield Stress (MPa)	Cycle Soaking (Toluene)
Unsoaked	14.03	Unsoaked	14.03	Unsoaked	14.03	Unsoaked
2 Weeks	13.83	2 Weeks	11.40	20	13.60	20
4 Weeks	11.00	4 Weeks	10.13	40	15.43	40
				60	11.83	60
				80	12.30	80
				100	13.87	100

Table 3: Yield Stress data for TPE samples obtained through uniaxial tensile testing.

TPE						
Long Soak (Acetone)	Average Yield Stress (MPa)	Long Soak (Toluene)	Average Yield Stress (MPa)	Cycle Soaking (Acetone)	Average Yield Stress (MPa)	Cycle Soaking (Toluene)
Unsoaked	10.10	Unsoaked	10.10	Unsoaked	10.10	Unsoaked
2 Weeks	13.97	2 Weeks	16.57	20	12.97	20
4 Weeks	12.13	4 Weeks	11.57	40	13.83	40
				60	11.50	60
				80	12.67	80
				100	14.17	100

Table 4: Yield Stress data for UHMWPE samples obtained through uniaxial tensile testing.

UHMWPE						
Long Soak (Acetone)	Average Yield Stress (MPa)	Long Soak (Toluene)	Average Yield Stress (MPa)	Cycle Soaking (Acetone)	Average Yield Stress (MPa)	Cycle Soaking (Toluene)
Unsoaked	14.27	Unsoaked	14.27	Unsoaked	14.27	Unsoaked
2 Weeks	15.60	2 Weeks	18.27	20	17.83	20
4 Weeks	17.43	4 Weeks	14.50	40	19.17	40
				60	14.97	60
				80	16.67	80
				100	17.57	100

Tables 1-4 show the results of tensile testing of each polymer under each soaking condition. For each soaking condition, a student's t-test was used to determine if there was a statistically significant difference between the unsoaked samples and the soaked samples. For each and every t-test, we could not reject the null hypothesis and therefore could not say that there was a statistically significant difference in tensile strength between the unsoaked and soaked tensile samples. Therefore, tensile testing could not be used to eliminate any of the four remaining polymers. Since optical microscopy and tensile testing yielded no evidence that any of the polymers had degraded, we attempted to use FTIR as a method to determine if there was any change in bond integrity over the course of soaking.

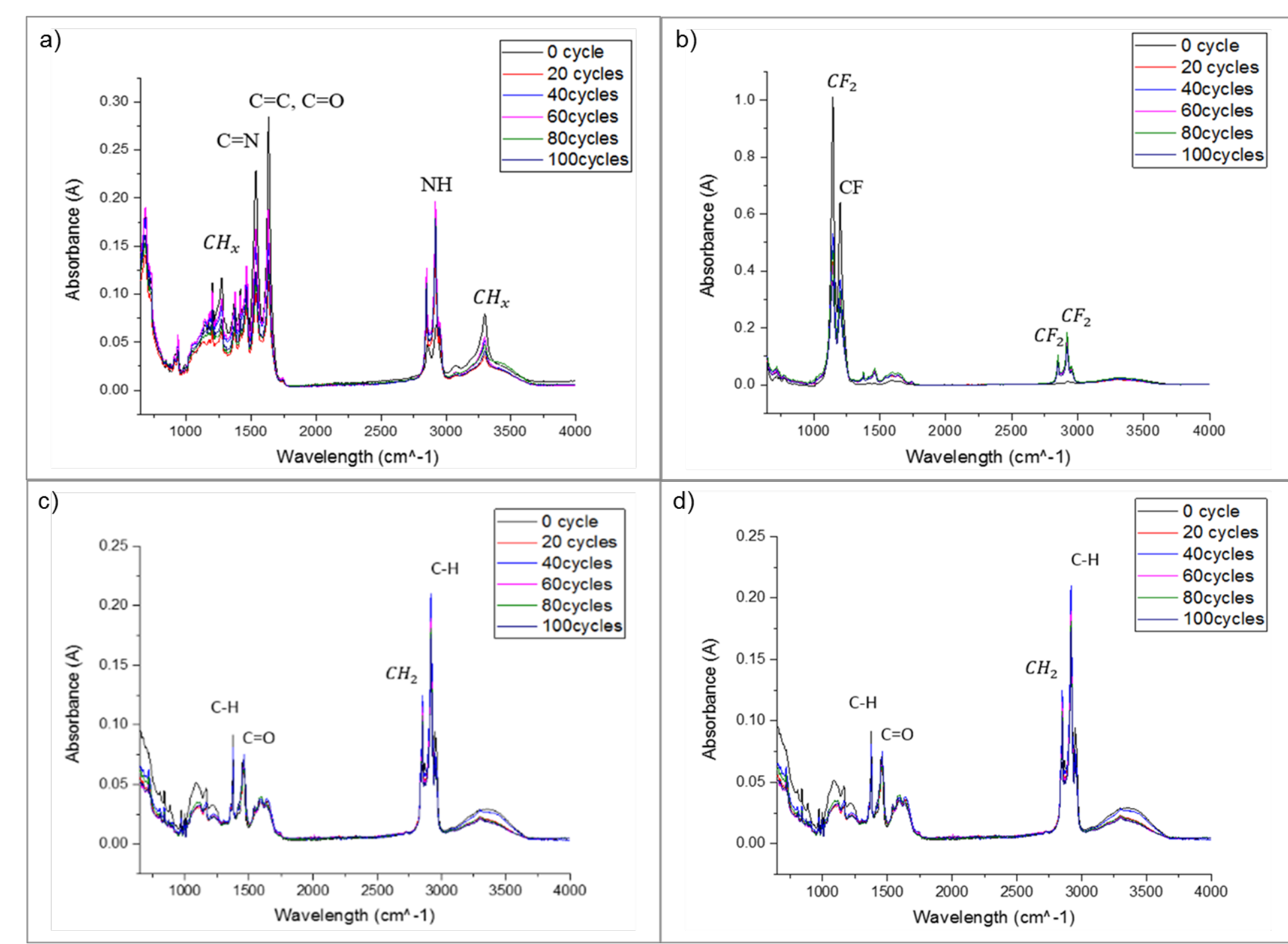


Figure 9: FTIR Spectrum of interval soaked (acetone) a) Nylon 6/6 b) PTFE c) TPE d) UHMWPE

Figure 9 shows the FTIR Spectra of each of the four polymers at each step of 100 cycles of soaking in acetone. In order to determine if any degradation had occurred, we were hoping to see a linear decrease in peak intensity over time. This would indicate that the bond integrity of the polymer was degrading over time in a consistent manner as a result of soaking. Unfortunately, this did not occur. While some slight changes in peak intensity occurred, the changes were not predictable, miniscule and difficult to interpret. Therefore, we were unable to use FTIR to determine that any significant degradation occurred. With the results of optical microscopy, tensile testing, and FTIR showing no significant degradation, we were unable to cause any of the four remaining polymers to degrade as a result of soaking. Therefore, we decided to determine the best masking material by cost rather than the mechanical and structural properties.

Table 5: Cost Analysis

Process	kWh/kg Produced
Compression Molding	3.168
Injection Molding	3.117

Polymer	Production Method	Energy (\$/mask)	Resin (\$/mask)	Mold Cost (\$)	Units Necessary to Achieve \$5/Mask
Nylon	Injection Molding	0.0024	0.0212	2,824,000	565
TPE	Injection Molding	0.0091	0.1950	2,824,000	565
UHMWPE	Compression Molding	0.0020	0.0144	2,824,000	565
PTFE	Compression Molding	0.0047	0.1945	2,824,000	565



Figure 10: Representative mask created using SolidWorks

Table 5 shows the results of our cost analysis. Since none of the remaining four polymers showed any signs of degradation after 4 weeks of long-term soaking or 100 cycles of interval soaking, we decided to say that each mask could only be used for 100 cycles, or the production of 100 hip stems. In order to calculate values based on a mask very similar to DePuy's hip stems, we created our own mask as is shown in Figure 10. Using the dimensions of this representative mask, we calculated the energy and resin costs/mask and obtained a quote to estimate mold tooling costs. Energy cost/mask for each polymer was calculated using the following equation:

$$E = \text{Average Specific Energy} + V_{\text{mask}} \cdot \rho_{\text{mask}} \cdot \text{Cost of Electricity}$$

where average specific energy is equal to 3.168 or 3.117 for compression and injection molding respectively as reported by the Center for Plastic Processing Technology at UW-Platteville, V is the volume of the mask, ρ is the density of the polymer, and the cost of electricity is equal to the national average of \$0.12/kWh. The resin cost/mask was calculated using the following equation:

$$R = \text{Average Resin Cost} + m_{\text{mask}}$$

where the average resin costs is reported in \$/kg by CES Edupack and m is the mass of the part as calculated by multiplying the volume by the density of the polymer. Once we had calculated the cost/mask of energy and raw materials, we obtained a quote from Xcentric Mold, a company that specializes in plastic production. We used this quote as our tooling costs for both injection and compression molding due to the similar mold structures of the two properties. Once we received the quote, we determine the number of masks that needed to be produced in order to meet the \$5/minimum per part for each polymer.

Recommendations

Overall, it was proven that polymers which are chemically inert to acetone and toluene could withstand both long duration and cyclic soaking to a large extent. UHMWPE, PTFE, NYLON 6/6, and TPE are suitable materials for use as reusable masks. Since little to no measurable changes occurred in the polymers after 4 weeks of soaking and 100 cycles of interval soaking respectively, we believe that the polymer to be used should be chosen based on ease of processing and cost of production. In examining the cost analysis, it is clear that UHMWPE has the lowest energy and resin costs. However, UHMWPE can only be produced by compression molding. This is an issue because compression molding is not suitable for complex shapes (i.e. a tapered hip stem) and has difficulty in producing parts with high precision due to flashing. Injection molding does not have these issues and can produce parts with complex shapes with a high degree of accuracy and precision. In looking at the two injection moldable polymers, it is clear that Nylon 6/6 is much cheaper and much easier to produce. Therefore, we recommend that DePuy choose Nylon 6/6 as the material with which to mask their hip stems in the coating process.

Future Work

Based on the work conducted in this project, Nylon 6/6 was the best material for this application. However, this may not truly be the case. After 4 weeks of interval soaking and also after 100 cycles of interval soaking, Nylon 6/6, PTFE, TPE, and UHMWPE showed no degradation as a result of soaking. Therefore, we chose cost and processing as the metrics of choice. However, if we were able to determine the actual lifespan of each polymer in this application we may have chosen a different polymer. For example, if PTFE cost more than Nylon 6/6 but lasts for 1000 more hip stems it may be the better material. Therefore, we recommend that in the future DePuy consider conduct longer or accelerated aging tests in order to determine a polymer that is truly the cheapest for the lifespan of each mask produced.

