UROP- Annealed 3D printed parts- Final Write up

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Abstract

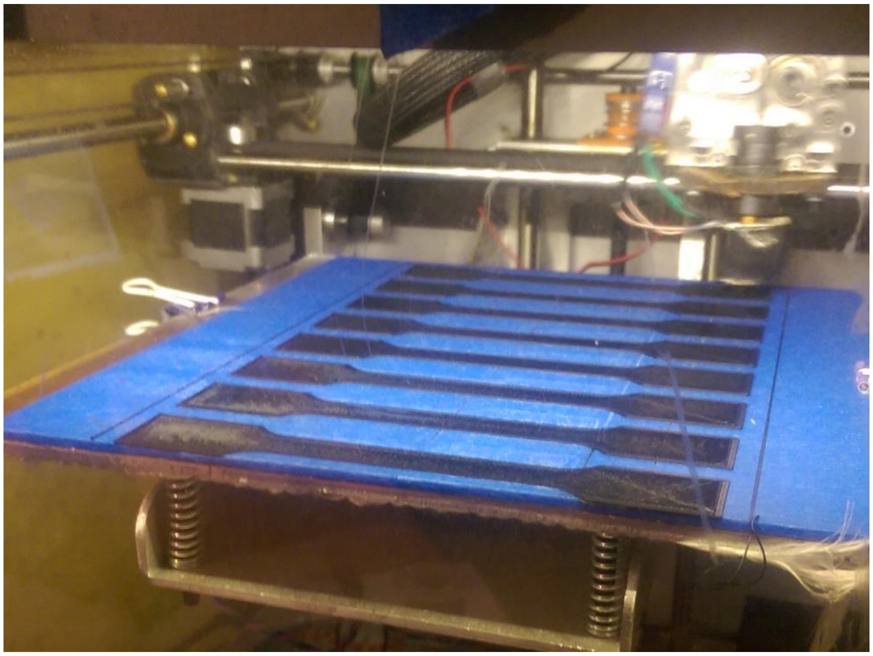
The purpose of this study was to examine the effects of a basic annealing process on 3D printed tensile test samples. Several different materials and annealing processes were used to determine the effect on the mechanical properties of 3D printed samples. With temperatures ranging from 170 to 200 F and times ranging from 10 to 60 minutes, over 100 samples were tested to create a large sample set. These samples were then tested in an Instron tensile testing machine to determine their tensile behavior. The overall results from the experiment showed very little affect from the annealing process, with an average increase close to 10% for tensile strength for ABS and about 5% for PLA. The change in the strain at failure showed a large amount of variation. The ABS samples displayed no real correlation for change in strain at failure. The PLA samples had a slight trend, leading to an average decrease of about 14% for the strain at failure. If anything the study showed that there is no real benefit to annealing 3D printed parts, and that they have a large variation in quality.

Introduction

After finding past research into the topic of annealing 3D printed parts, it seemed reasonable to study this topic even further with this UROP project. The basic idea behind annealing an object is to favorably change the mechanical properties of the material to better suit the needs of a design. In this case either stiffening or softening the part would have been desirable traits. Stiffer samples would lead to stronger but more brittle parts, which have application in some instances. Softening the part would have increased ductility while decreasing the overall tensile strength. This should lead to a tougher part that is less susceptible to fracture when dropped, repeatedly loaded, etc. This was the result that was originally predicted for the two materials tested.

Method

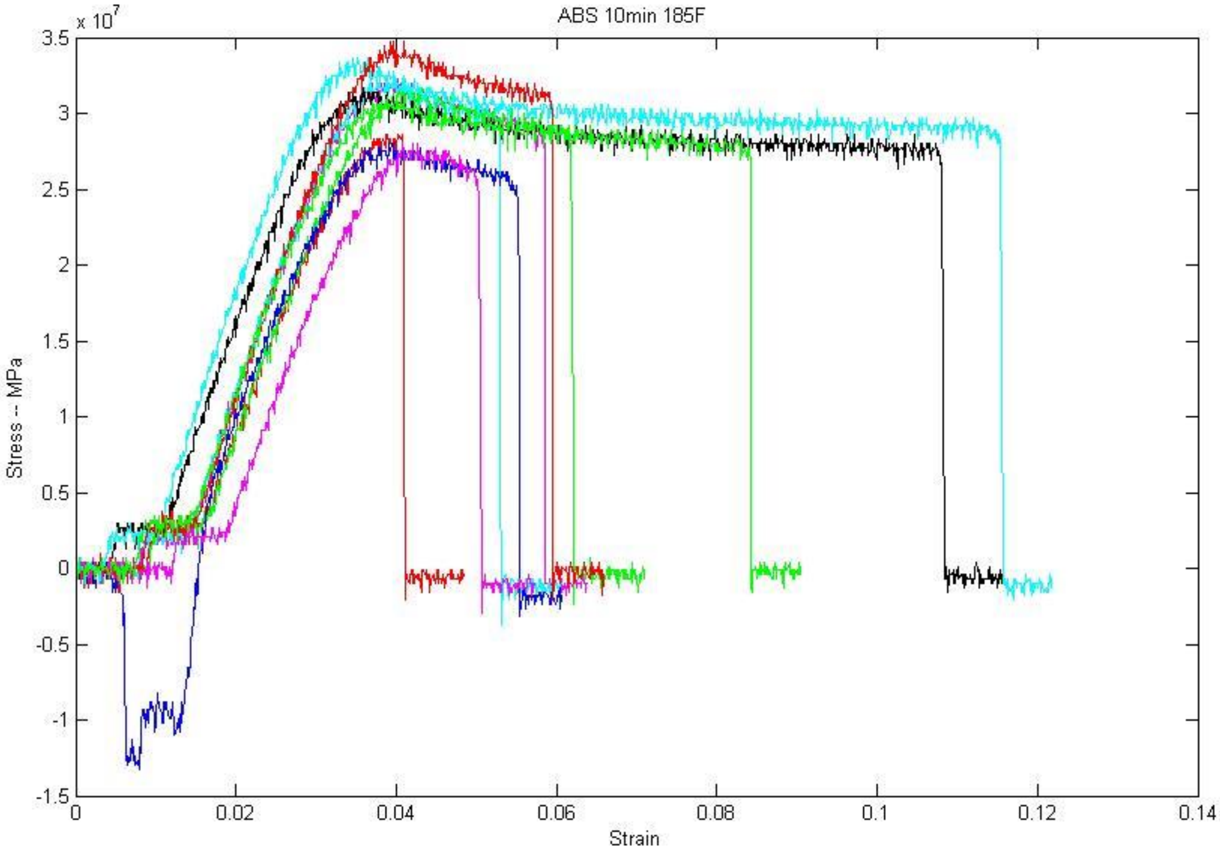
Two different materials were examined: PLA (polylactic acid) and ABS (acrylonitrile butadiene styrene). These materials were purchased from ProtoParadigm, an online 3D printing filament retailer. The printer used was a solidoodle 3 in stock configuration. The samples were a model of a flat dog bone designed to be 1x10mm in cross sectional area. The pull section was 75mm long with widened tabs for the jaws to clamp to.

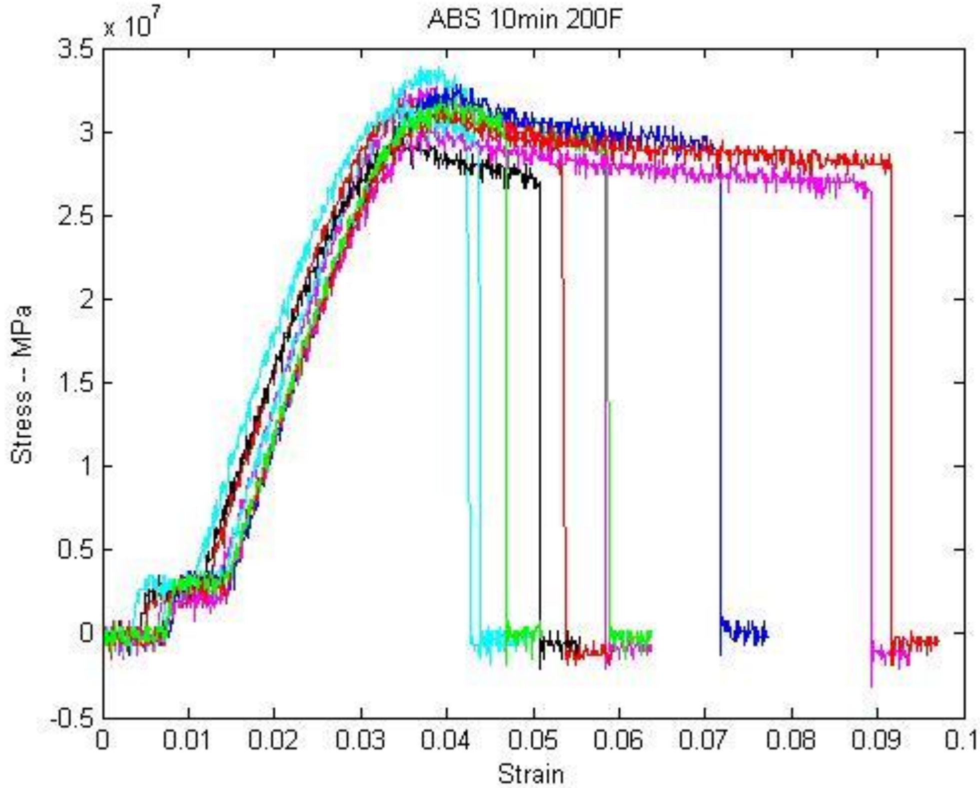


The annealing process was carried out in an electric home oven. For this experiment, two temperatures (185 and 200F) and three lengths of time (10, 30, and 60 minutes) were chosen for the ABS samples. Due to the lower melt temperature of PLA, only one temperature was used (170F) with the same three time intervals used for the ABS samples. For each set, ten samples were tested, all going through the exact same process. Ten samples were also created for each material that didn't undergo any treatment to act as control. All the samples were reviewed carefully before being selected to check for obvious flaws to deal with issues found in previous tests. The samples were placed onto a metal tray in the oven. Each set experienced a 3 minute ramp up period where the temperature increased linearly. After the annealing time, the oven was turned off and the samples were left to cool slowly in the oven for an hour. After the cool down time the samples were removed from the oven and labeled for testing. These samples were brought to the polymer research lab in Amundson Hall to be tested. An Instron testing machine was used to pull the samples at 10mm/min. Each sample was loaded identically into the machine. The stress versus strain curve was recorded into an excel spreadsheet for each sample. This data was then processed to determine the results of the study.

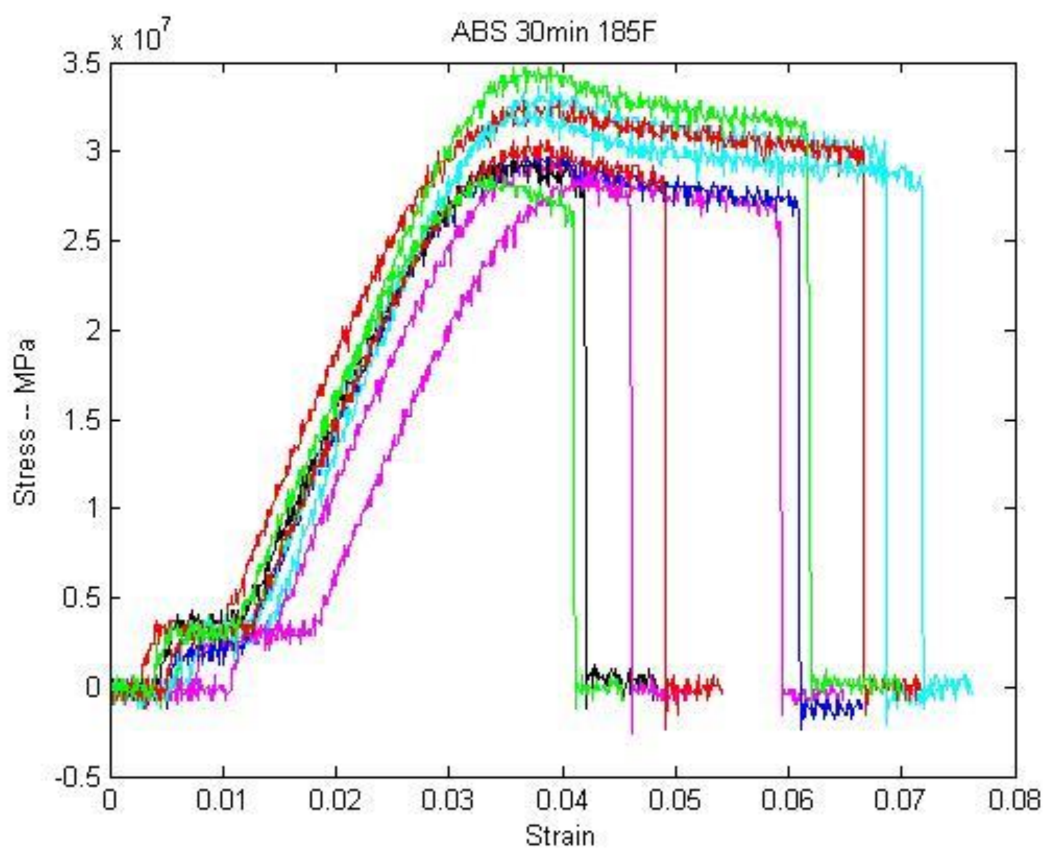
Results

The data was from the tests was then placed into graphs showing stress vs. strain for each data set.

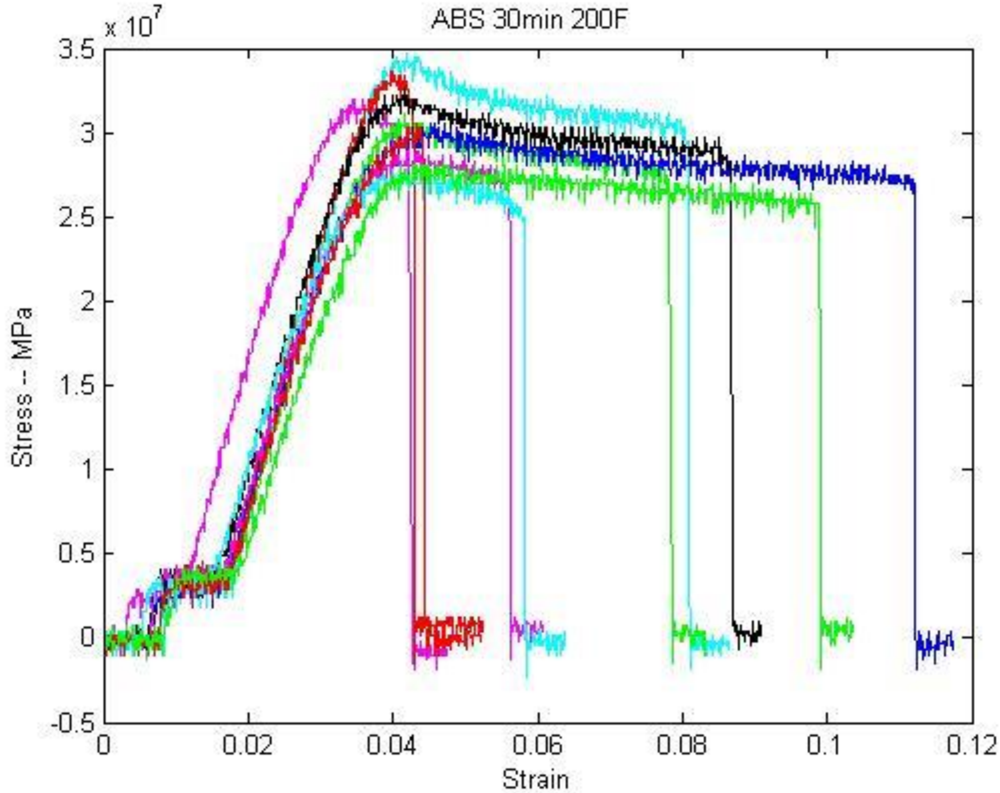


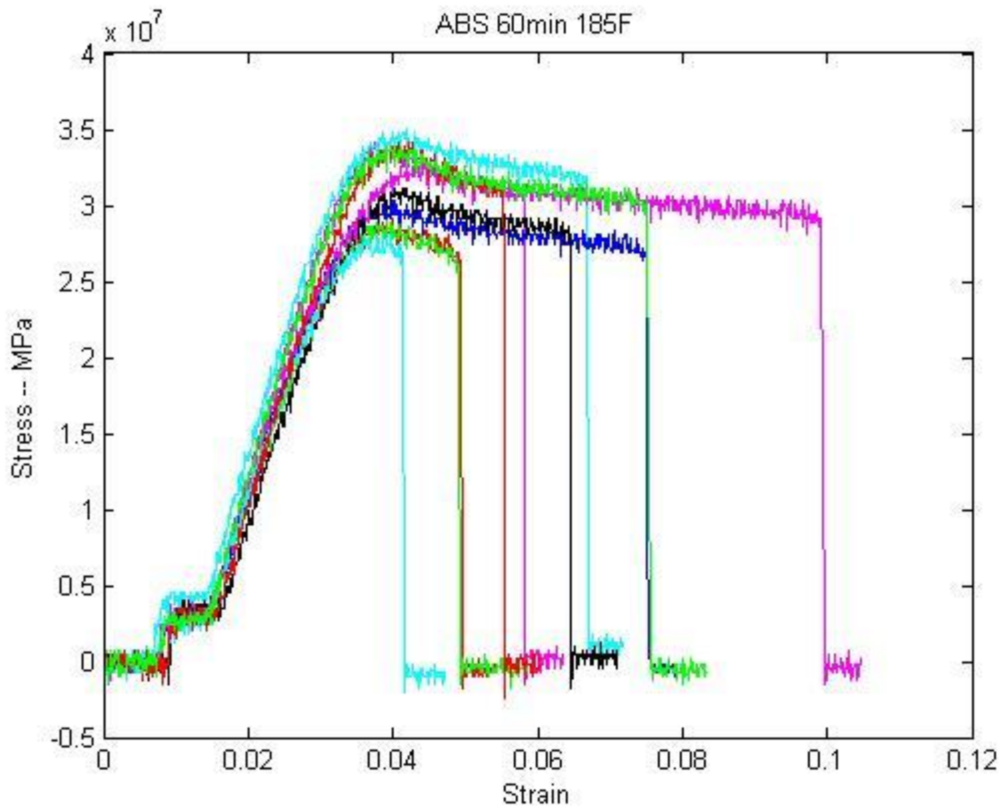


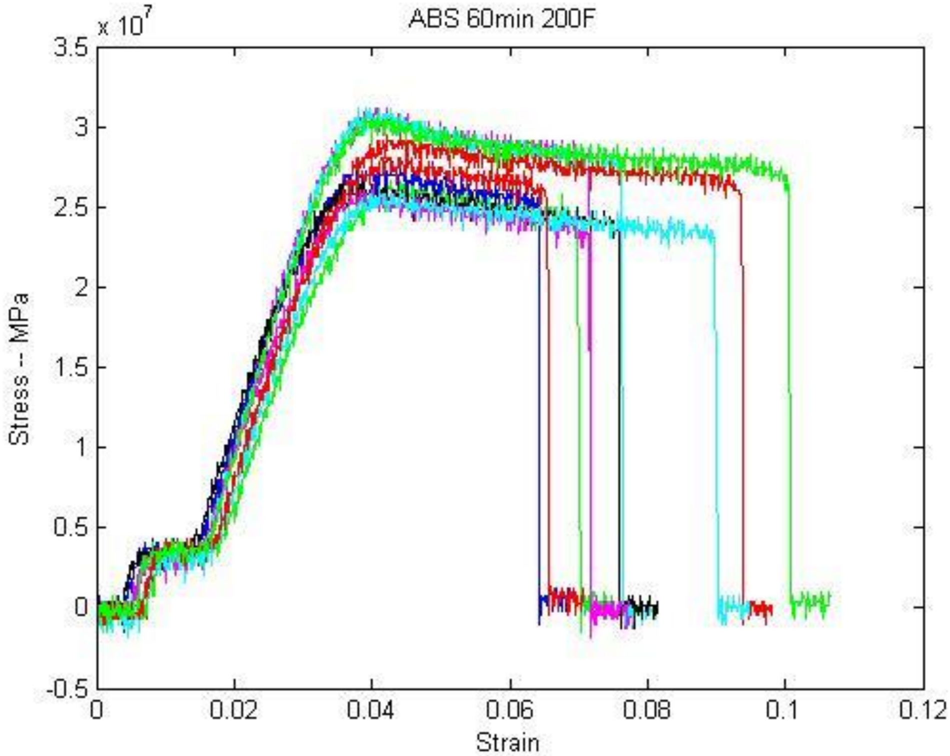
ABS 10min 200F
x 10^7
Stress -- MPa
Strain



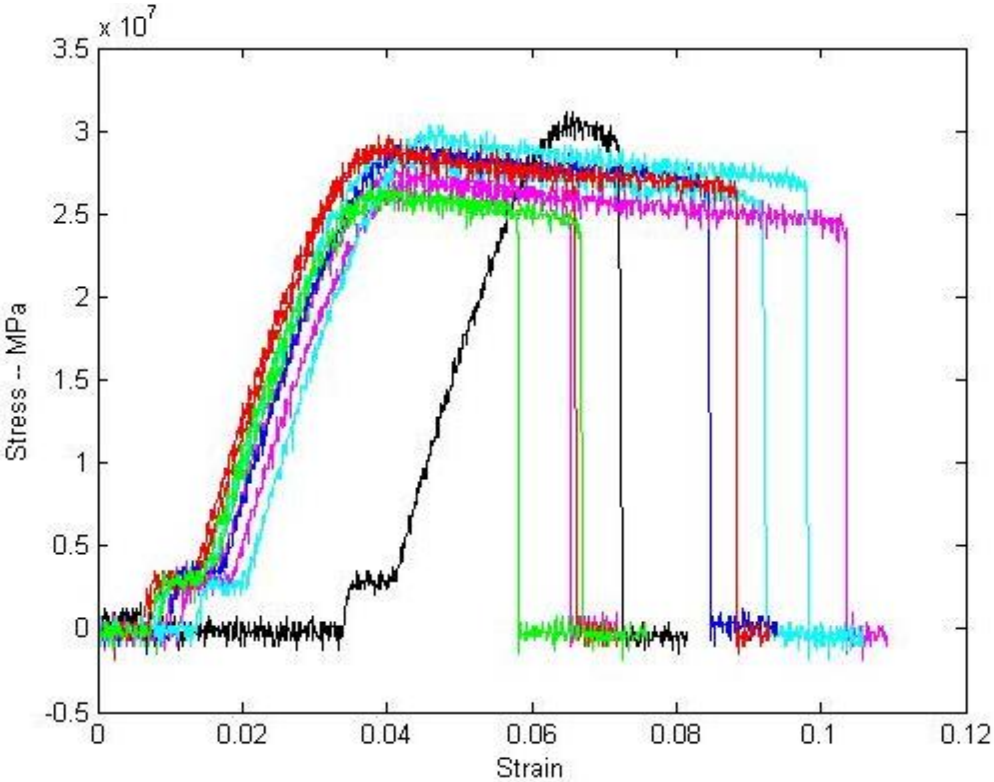
ABS 30min 185F
x 10^7
Stress -- MPa
Strain


ABS 30min 200F
x 10^7
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
Stress -- MPa
0
0.02
0.04
0.06
0.08
0.1
0.12
Strain


ABS 60min 185F
x 10^7
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
Stress -- MPa
0
0.02
0.04
0.06
0.08
0.1
0.12
Strain


ABS 60min 200F
x 10^7
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
Stress -- MPa
0
0.02
0.04
0.06
0.08
0.1
0.12
Strain

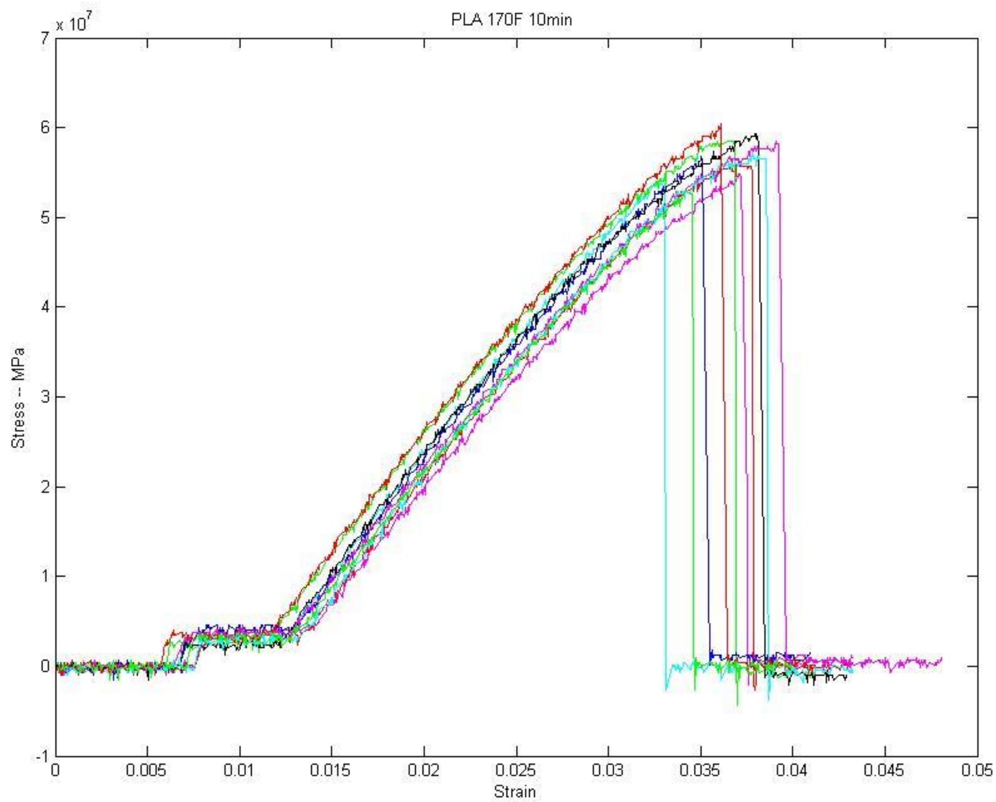
ABS Control

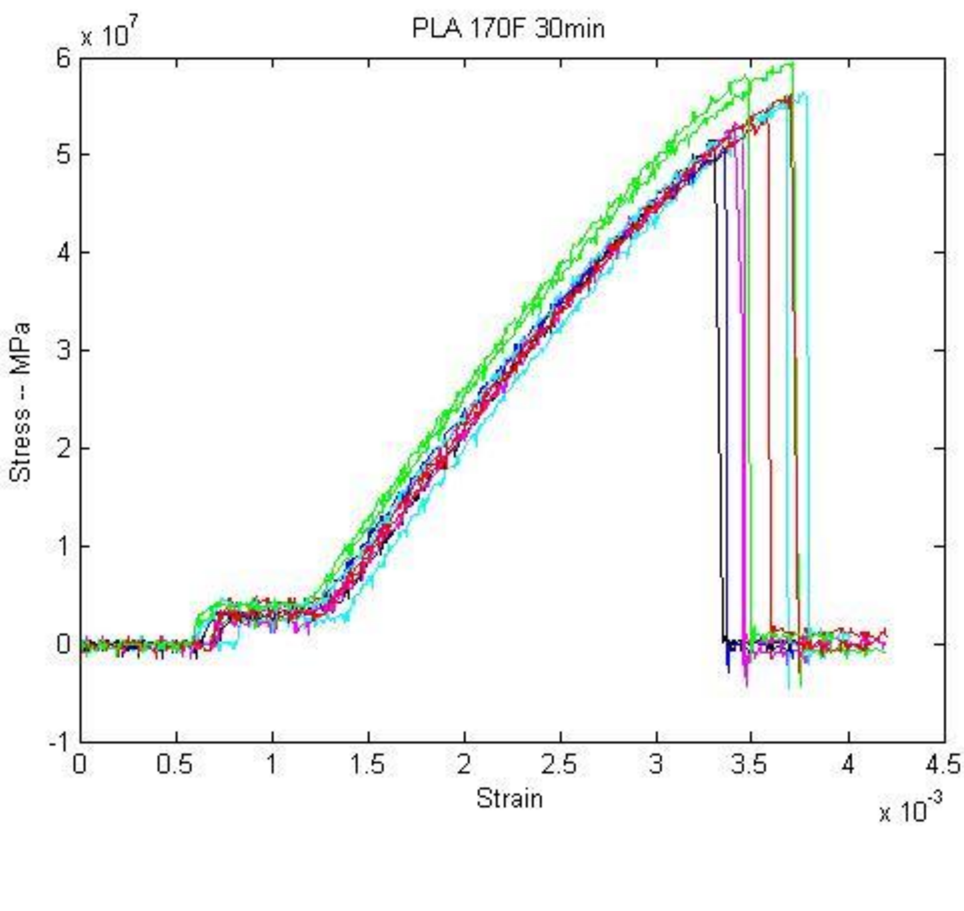

x 10^7
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
Stress -- MPa
0
0.02
0.04
0.06
0.08
0.1
0.12
Strain

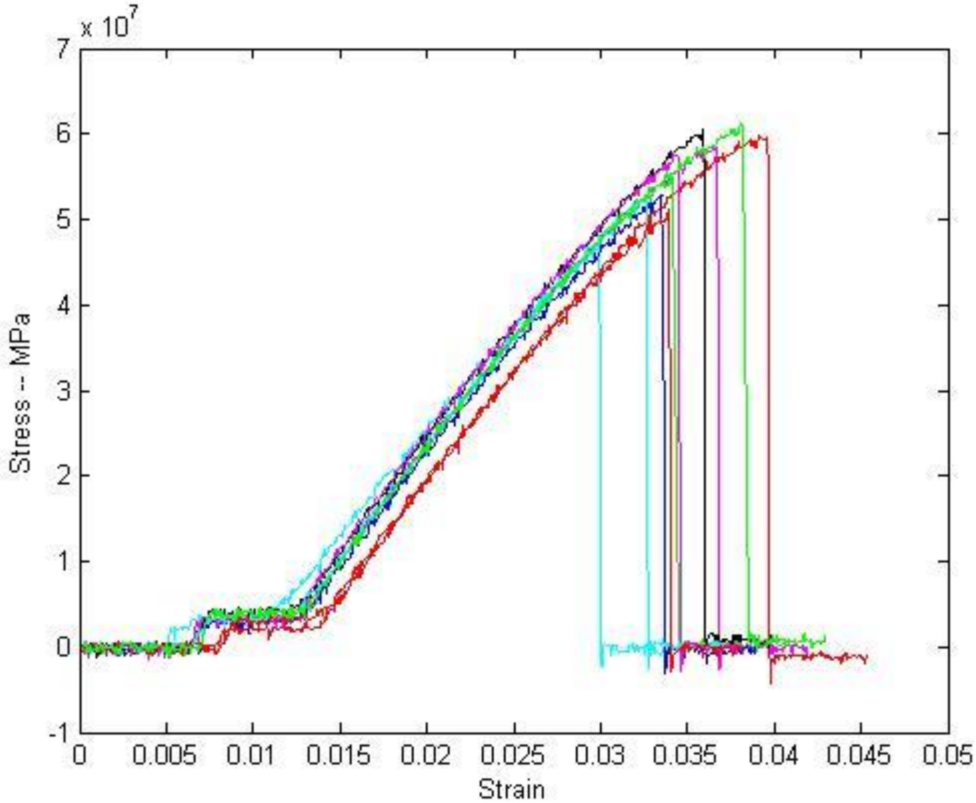
	UTS (Mpa)	Strain AB	difference	
ABS control	2.8180	0.0761	UTS (Mpa)	Strain AB
ABS 10min 185F	3.0880	0.0687	0.2700	-0.0074
ABS 10min 200F	3.1280	0.0619	0.3100	-0.0142
ABS 30min 185F	3.0680	0.0567	0.2500	-0.0194
ABS 30min 200F	3.0470	0.0701	0.2290	-0.0060
ABS 60min 185F	3.1300	0.0634	0.3120	-0.0127
ABS 60min 200F	2.7990	0.0808	-0.0190	0.0047

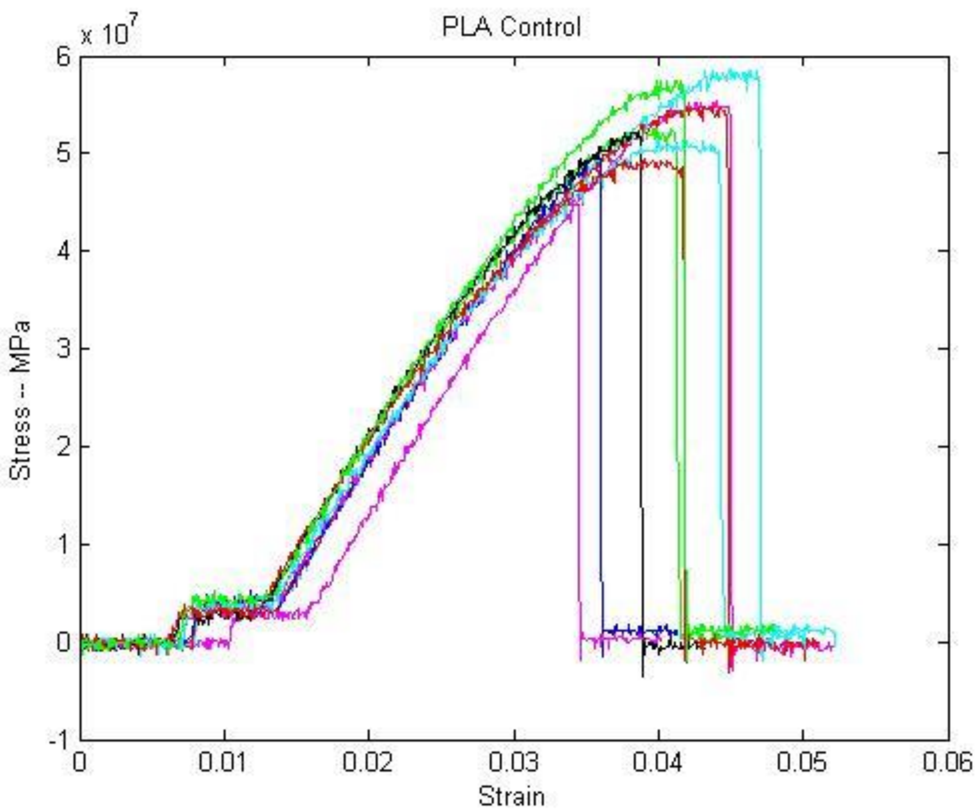
percent change		185 strain	200 strain
UTS (Mpa)	Strain AB	-9.69	-18.69
9.58	-9.69	-25.51	-7.85
11.00	-18.69	-16.64	6.14
8.87	-25.51	185 strength	200 strength
8.13	-7.85	9.58	11.00
11.07	-16.64	8.87	8.13
-0.67	6.14	8.13	-0.67

Standard Dev.				
Samples	UTS (Mpa)	Percent SD	Strain AB	Percent SD
ABS 10min 185F	0.2163	7.00	0.0239	34.83
ABS 10min 200F	0.1225	3.92	0.0163	26.34
ABS 30min 185F	0.1921	6.26	0.0107	18.94
ABS 30min 200F	0.2103	6.90	0.0236	33.69
ABS 60min 185F	0.2427	7.75	0.0160	25.25
ABS 60min 200F	0.2018	7.21	0.0119	14.69


PLA 170F 10min
x 10^7
7
6
5
4
3
2
1
0
-1
Stress -- MPa
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05
Strain


PLA 170F 30min
x 10^7
6
5
4
3
2
1
0
-1
Stress -- MPa
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Strain
x 10^-3


x 10^7
Stress -- MPa
Strain
7
6
5
4
3
2
1
0
-1
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05


PLA Control
x 10^7
Stress -- MPa
Strain
6
5
4
3
2
1
0
-1
0
0.01
0.02
0.03
0.04
0.05
0.06

	UTS (Mpa)	Strain AB	difference		percent change	
PLA control	5.205	0.0415	UTS (Mpa)	Strain AB	UTS (Mpa)	Strain AB
PLA 10min 170F	5.646	0.0367	0.4410	-0.0048	7.8108	-11.6358
PLA 30min 170F	5.447	0.0358	0.2420	-0.0058	4.4428	-13.8689
PLA 60min 170F	5.502	0.0349	0.2970	-0.0066	5.3980	-15.8516

Standard Dev.				
Samples	UTS (Mpa)	Percent SD	Strain AB	Percent SD
PLA 10min 170F	0.2205	3.91	0.0019	5.11
PLA 30min 170F	0.2675	4.91	0.0016	4.38
PLA 60min 170F	0.4448	8.08	0.0027	7.62

Discussion

As one can see from both the graphs and tables for ABS, there was a huge amount of variation within the data, especially when looking at the strain at break. Standard deviation was translated to percent to make better sense of the incredibly small number. With standard deviation units as high as 35% of the entire value for strain, it’s nearly impossible to pull any reliable or meaningful data from these results, though there was a trend that the ductility decreased from the annealing process. While there was a huge amount of variation for the strain at break, the ultimate tensile strengths for the samples were relatively stable, leading to much more consistent data. In almost all cases, a slight increase in tensile strength (about 10% compared to the control group) resulted from all the annealing processes, except for the 60min at 200F samples which were outliers. There was no time dependence related to either tensile strength or strain at break as the data had no related trends. One strong conclusion that can be drawn from the ABS test is that the quality of the parts vary greatly. This could lead to issues when reliability between parts is required for a design.

After processing the PLA data, an interesting change in consistency occurs. Instead of the huge variation seen in the ABS samples, the PLA sets actually have very consistent results. Unfortunately there were very small changes in tensile strength and strain when compared to the control set. Leading to an increase of about 5% in tensile strength with a 15% loss in strain at break. These results show that again, there is little value in annealing 3D printed samples, though it should be noted that PLA has more consistent mechanical properties compared to ABS.

Conclusion

After this extensive study into the effects of annealing on 3D printed parts’ mechanical properties, it has been found that there is little value in the process for any purpose. The properties simply didn’t change that much after averaging the values over data sets of ten with temperature or length of annealing time. The most interesting part about the experiment was how varied the ABS samples were in general and how consistent the PLA samples were. With further testing this could lead to the conclusion that ABS is a less stable printing material, yielding less consistent results compared to PLA. This could have a large effect on choice of material when consistency between pieces is required. One theory I came up with to explain the ineffectiveness of the annealing process is that since the part sits on a hot piece of glass in a relatively hot environment, the parts may already be 'annealed' due to the printing process. After being printed for a long time in a hot environment the parts may be annealed to some extent. Making further processing unnecessary.