Study on Estimation of Mechanical Properties of FDM-based 3D Printing Parts

Heechang Kim, Suhyun Kim, Eunju Park, Namhun Kim, Seungchul Lee*

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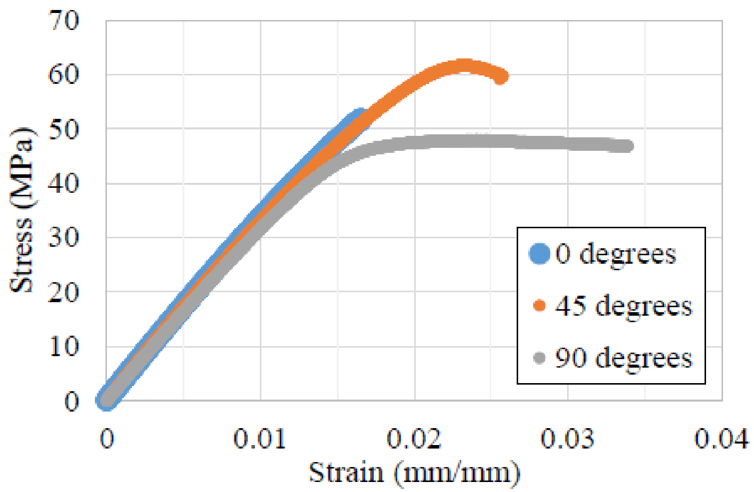
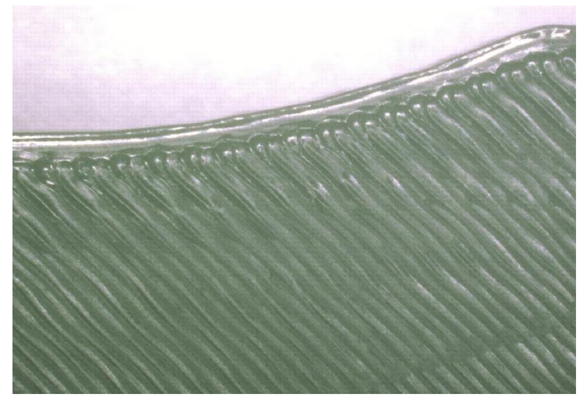
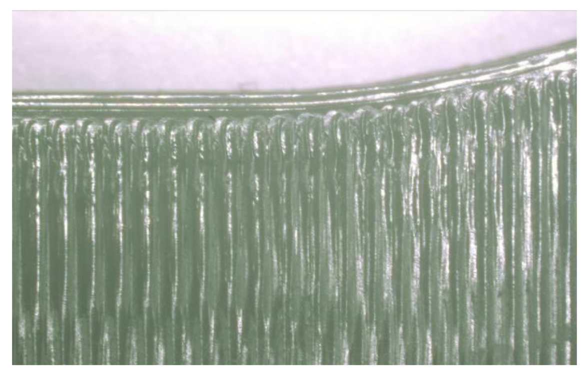
Literature Review

- Ref. Letcher et al., **Material property testing of 3D printed specimen in PLA on an entry-level 3D printer,** *ASME 2014 International Mechanical Engineering Congress & Exposition*



Raster Orientation (degrees)	Average Ultimate Stress (MPa)	Average Elongation at Break (%)	Average Modulus of Elasticity (GPa)
0	58.45	2.02%	3.33
45	64.03	2.50%	3.60
90	54.01	4.14%	3.49





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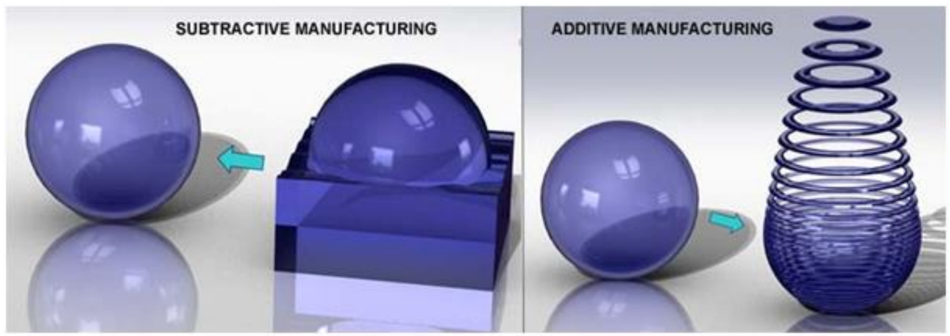
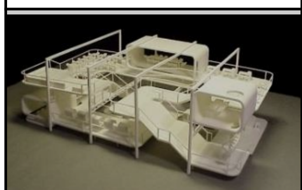
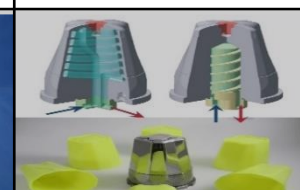
Outline

- Introduction
- Motivation
- Experiment
- Results and Discussion
- Estimation of Maximum Tensile Stress
- Conclusion

Additive Manufacturing (AM)

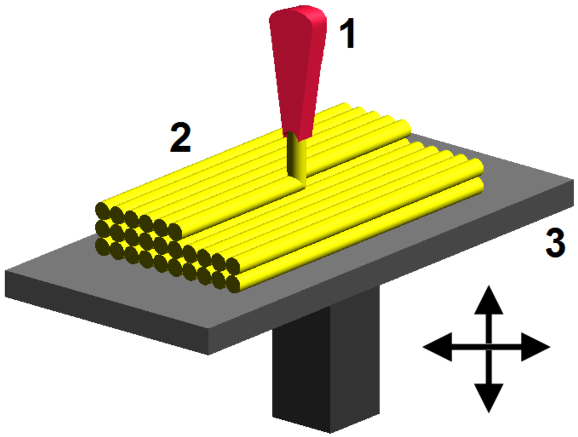
- Automated systems that take 2D layers of computer data and rebuild them into 3D products



Rapid Prototyping	Aerospace	Medical	Tooling	Lifestyle	Automotive
					

Fused Deposition Modeling (FDM)

- Advantages
  - A good variety of materials available
  - Easy material change
  - Low maintenance costs
  - Thin parts produced fast



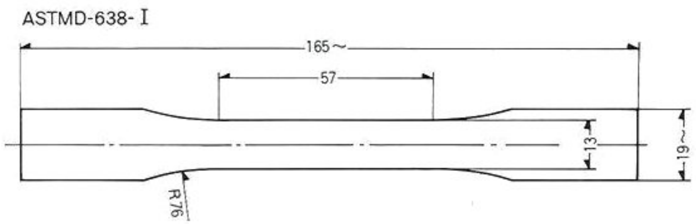
- Disadvantages
  - Seam line between layers
  - The extrusion head must continue moving, or else material bumps up
  - Supports may be required

Motivation

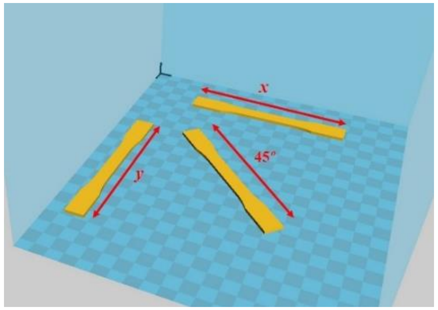
- Conventional processing vs. AM
  - The mechanical properties are relatively weak
- Mechanical properties are not known before printing
  - Only time, weight and required filament for the product is predicted in current software
- Necessity of estimation of mechanical properties
  - Optimal printing

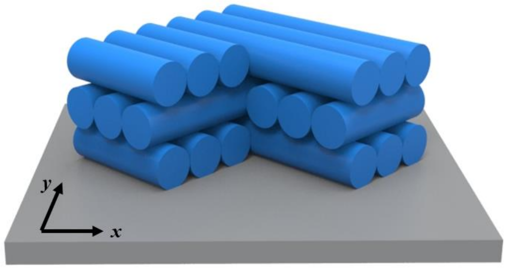
Experiment Settings

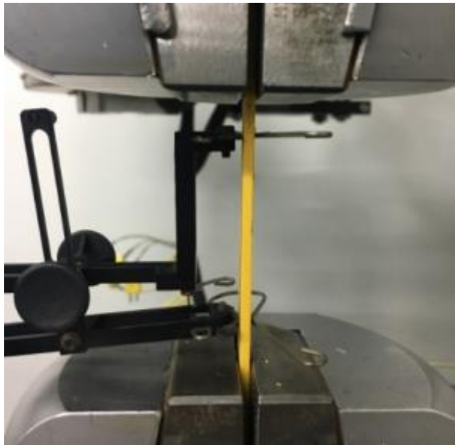
- Tensile Strength Test
  - ASTM D638



- Factors
  - Model: Sprout (Former's Farm)
  - Materials: ABS or PLA
  - Filament diameter: 1.75 mm
  - Nozzle diameter: 0.4 mm





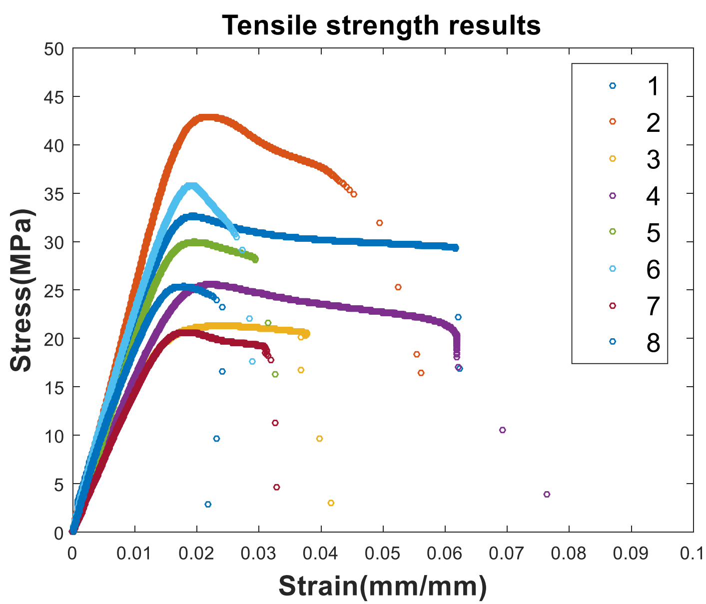


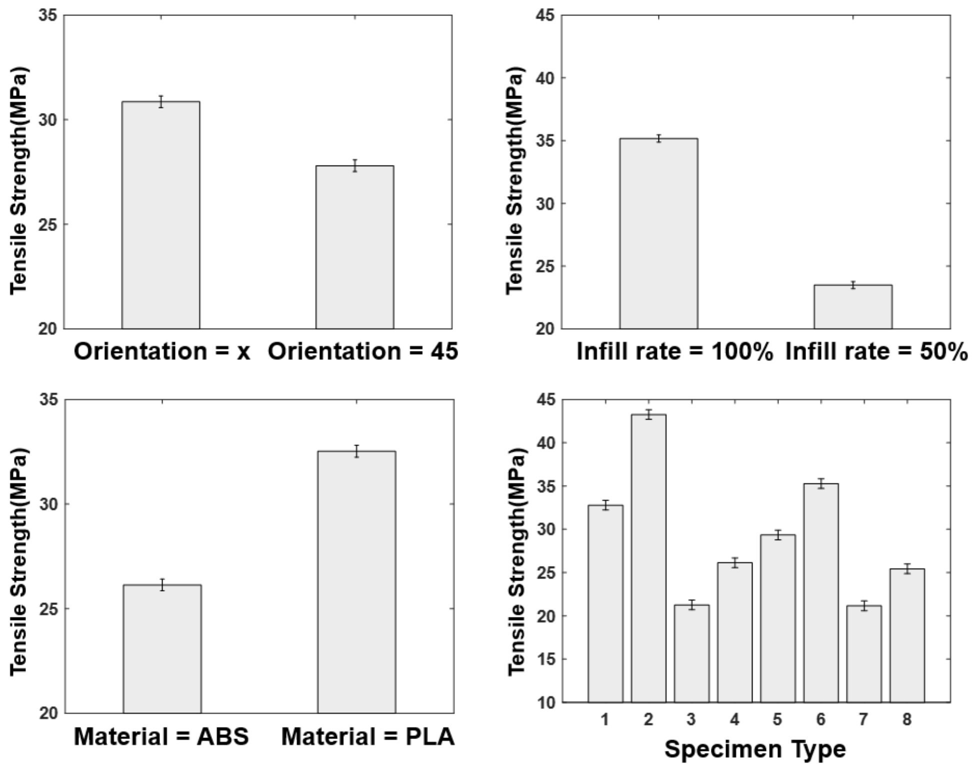
Factors	Description
Orientation	1) X-axis direction 2) 45°
Materials	1) ABS 2) PLA
Infill rate	1) 50% infill 2) 100% infill

Results

Factors	Description
Orientation	1. X-axis direction 2. 45°
Materials	1. ABS 2. PLA
Infill rate	1. 50% infill 2. 100% infill

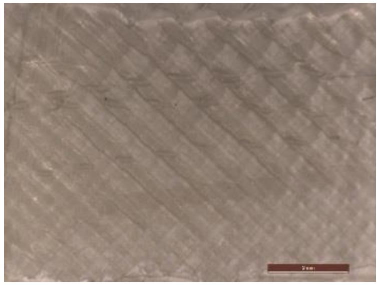
No.	Orientation	Materials	Infill rate
1)	1	1	1
2)	1	2	1
3)	1	1	2
4)	1	2	2
5)	2	1	1
6)	2	2	1
7)	2	1	2
8)	2	2	2



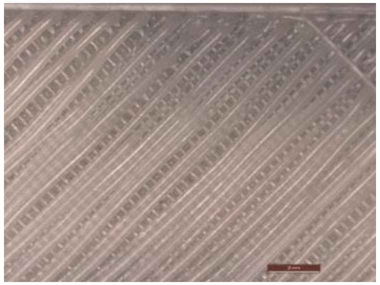


Discussion

- Infill rate

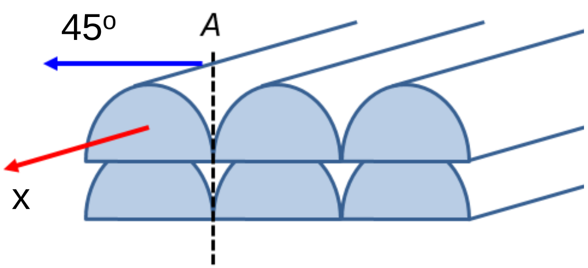


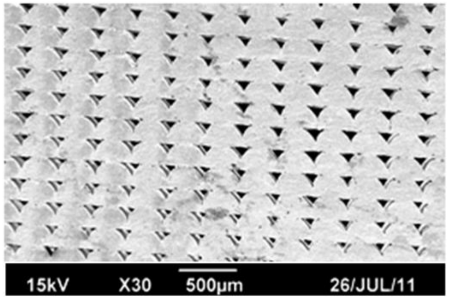
100%



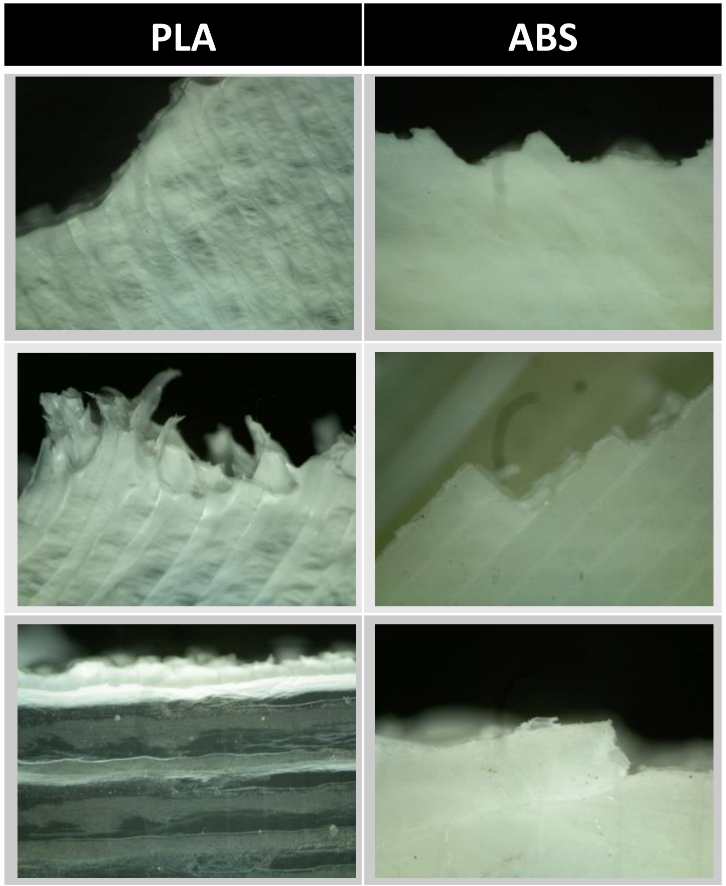
50%

- Cross section for orientation





Materials



Significant Factor

- ANOVA
  - The effect of orientation, material and infill rate

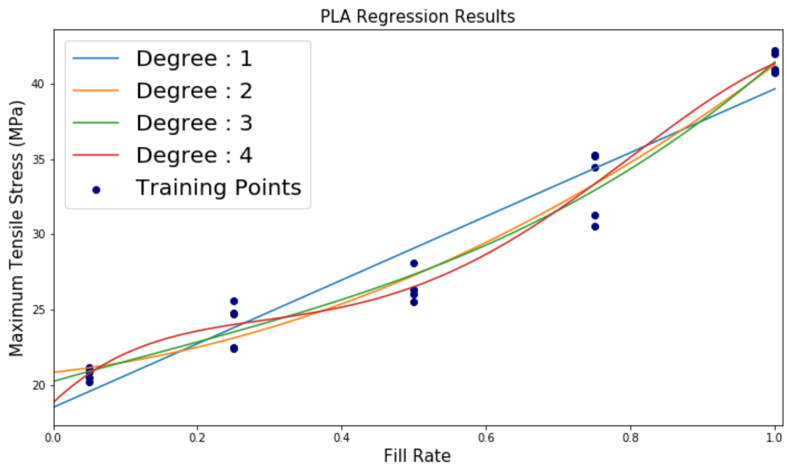
Control factors	Sum of square	Degree of freedom	F	Prob > F	Significance
Orientation	93.54	1	59.09	9.2048e-09	***
Material	1362.7	1	860.64	7.2177e-17	***
Infill rate	408.11	1	257.81	1.0554e-24	***
Orientation × Infill rate	70.63	1	44.62	1.5414e-07	***
Orientation × Materials	16.47	1	10.41	0.0027	***
Infill rate × Materials	33.04	1	20.87	6.9328e-05	***
Orientation × Infill rate × Material	9.74	1	6.15	0.0186	**
Error	50.66	32			
Total	2044.89	39			

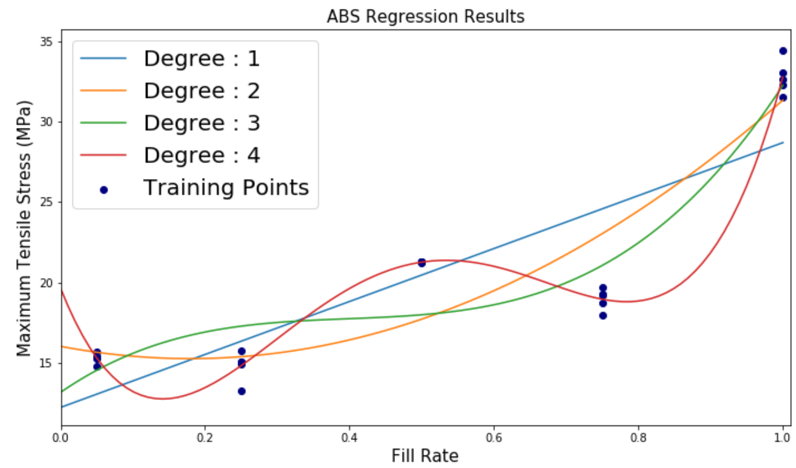
  - It shows which groups of the factors are significantly different
  - All factors have a significant difference

Factor	Difference	95% Confidence interval	
Material	6.39	5.58	7.20
Orientation	3.06	2.25	3.87
Infill rate	11.67	10.86	12.48

Estimation of Max. Tensile Stress

- Polynomial regression



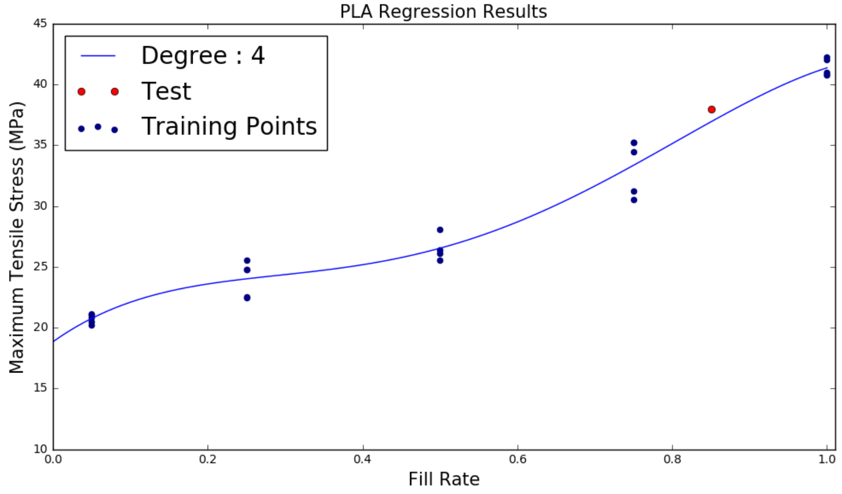


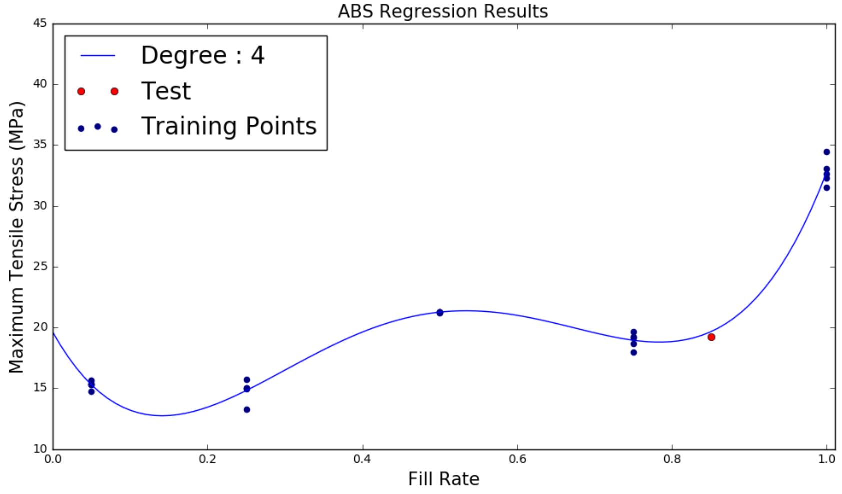
(MPa)

	5%	25%	50%	75%	100%
Max. Tensile Stress (PLA)	20.76	24.02	26.53	33.07	41.35
Max. Tensile Stress (ABS)	15.30	14.81	21.26	18.95	32.78

Estimation of Max. Tensile Stress

- Polynomial regression (degree: 4)

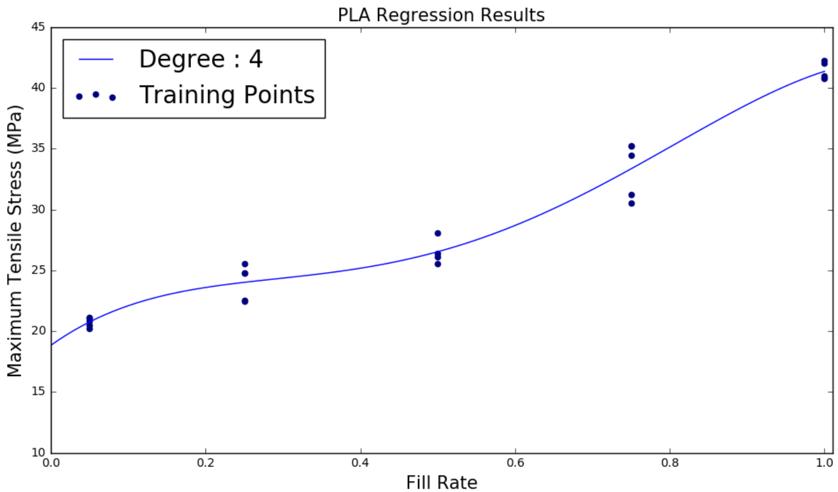


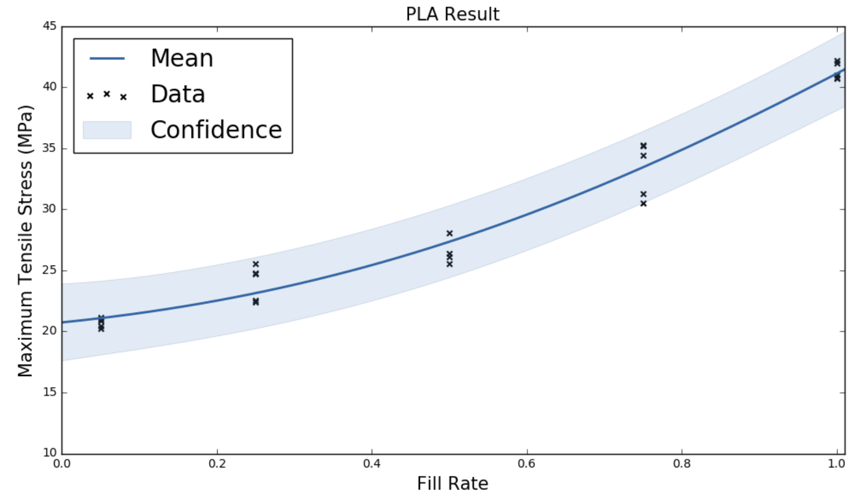


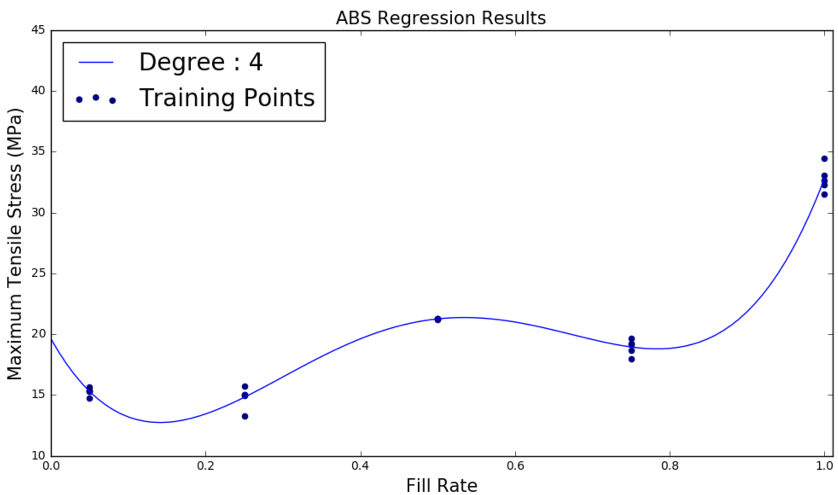
  - Polynomial regression model of degree 4 is well fitted
  - Extra experiment on 85% for verification
    - the error was 1.37%

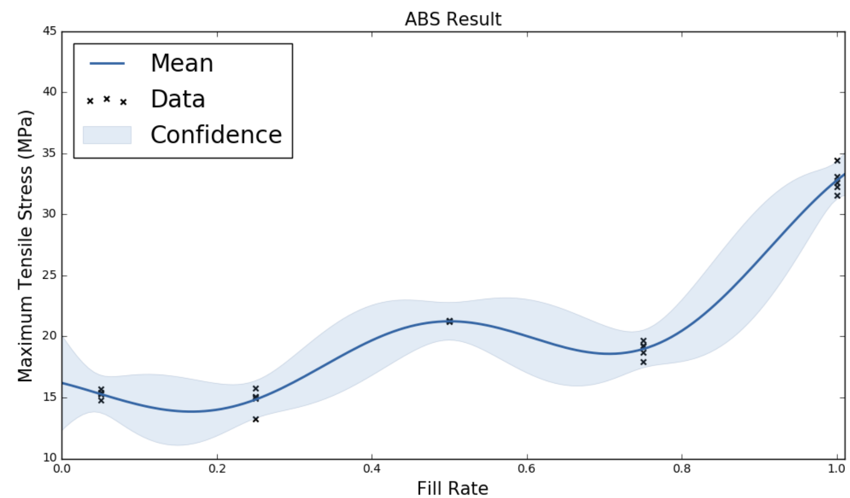
Gaussian Process Regression

- Uncertainty - On every fill rate range



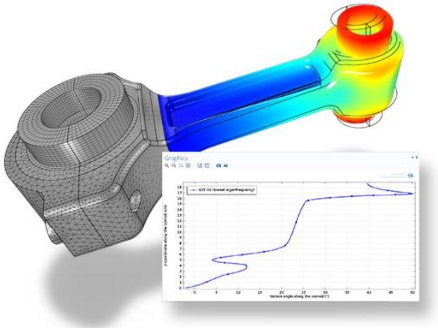




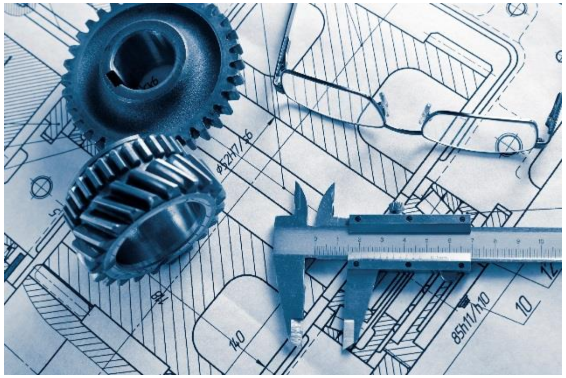


Conclusions

- Applications
  - Accurate structural mechanics design
    - Possible to design more improved stability in terms of structure using the estimated mechanical properties



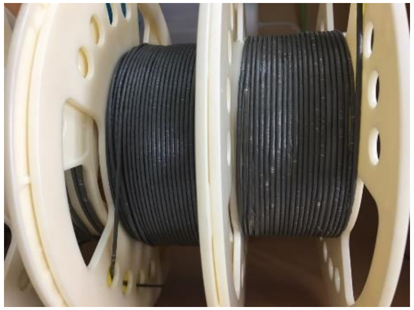
  - Safety device
    - When an excessive load is applied to a specific part, it can be used for safety device by designing it to break at a characteristic load or more



Future work

- **Preparation of the CF-filament**





- **Estimation considering various variables**