

Table of Content

1	Introduction	1
1.1	Scope of the Dissertation	7
1.2	Structure of the work	7
1.3	References	8
2	Production Process of Carbon Fiber	10
2.1	Precursor Production	12
2.1.1	Wet Spinning	12
2.1.2	Melt Spinning	13
2.1.3	Chemical Structure of a PAN Fiber	15
2.2	Precursor Stabilization	16
2.3	Carbonization Process	21
2.4	Graphitization Process	22
2.5	Surface treatment and Sizing	23
2.6	References	24
3	Precursor for Carbon Fiber	27
3.1	Commercial available Carbon Fiber Precursors	27
3.1.1	Polyacrylonitrile	27
3.1.2	Pitch	28
3.2	Alternative Precursors	30
3.2.1	Polyethylene	30
3.2.2	Cellulose	31
3.2.3	Lignin	35
3.3	Lignin as a Precursor for Carbon Fiber	36

3.4	Chemical Anatomy of Wood and Lignin	38
3.5	Isolation of Lignin from Wood	41
3.5.1	The Kraft Process	42
3.5.2	The Sulfite Process	43
3.5.3	The Organocell Process	44
3.5.4	The Alcell Process	45
3.5.5	Biorefinery	45
3.5.6	Influence of the pulping process on chemical structure	46
3.6	References	48
4	Properties and Chemical Characterization	52
4.1	Detection of the Properties of Lignin	52
4.1.1	Thermo Gravimetric Analysis	53
4.1.2	Differential Scanning Calorimeter	56
4.2	Chemical Characterization of Lignin	59
4.2.1	Elementary Analysis	59
4.2.2	Mass Spectroscopy	61
4.2.3	Nuclear Magnetic Resonance Spectroscopy	71
4.2.4	Fourier Transform Infrared Spectroscopy	81
4.3	Chemical Structure of Hardwood Lignin for carbon fiber production	85
4.4	References	88
5	Development of a Lignin Based Carbon Fiber	90
5.1	Lignin Powder	91
5.2	Compounding and Pelletizing	91
5.3	Precursor Fiber Production	93
5.4	Fiber Stabilization	95
5.5	Fiber Carbonization	97

5.6	References	98
6	Major reactions during conversion of lignin	99
6.1	Sample Characterization	99
6.2	Results	100
6.2.1	Nuclear Magnetic Resonance Spectroscopy	100
6.2.2	Fourier Transform Infrared Spectroscopy	110
6.2.3	Elementary Analysis	112
6.3	Major Reaction of Lignin during Conversion Process	113
6.3.1	Pelletizing of Lignin	113
6.3.2	Spinning of the Lignin Fiber	114
6.3.3	Stabilization of the Lignin Fiber	114
6.3.4	Carbonization of the Lignin Fiber	116
6.4	Conclusion	116
6.5	References	117
7	Properties and Chemical Structure	119
7.1	Properties of Lignin Based Carbon Fiber	119
7.1.1	Single Fiber Tensile Test	119
7.1.2	Density of Lignin Based Carbon Fiber	124
7.1.3	Scanning Electron Microscopy	126
7.2	Chemical Structure of Lignin Based Carbon Fiber	132
7.2.1	Raman Spectroscopy	132
7.2.2	X-ray Photoelectron Spectroscopy	138
7.3	Correlations between Properties and Chemical Structure of Lignin Based Carbon Fiber	144
7.4	References	146
8	Lignin and Conventional Carbon Fiber	148

8.1	Raman Spectroscopy	148
8.2	XPS Studies	150
8.3	Scanning Electron Microscopy	153
9	Potential of Lignin-Based Carbon Fiber	156
9.1	Economic and Ecological Potential of Lignin-Based Carbon Fiber	156
9.2	Possible products made from Lignin based Carbon Fiber in the near future	158
9.3	References	160
10	General Conclusions	161
10.1	Development of lignin based carbon fiber	161
10.2	Proof of industrial production size	162
10.3	Properties and chemical characterization	163
10.4	Economic and ecological potential of lignin based carbon fiber	164
10.5	Recommendations for future work	164
11	List of Publication	165
12	List of Abbreviations and Symbols	169
13	Appendix	174
13.1	Results of the Density Measurements	174