Properties of biochar from wood and textile

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Abstract. Due to population growth and economic activities, the increasing of generation and unreasonable disposal of waste biomass have been payed more attention than before. Traditional disposal methods may lead to environmental issues such as contaminating water and soil. This study explores the possibility of utilizing waste biomass to prepare biochar which can be used as addition in cementitious composites. This presents an obvious opportunity to recycle waste biomass as a construction material and use at large scale. In this study, wood and textile are feedstocks to prepare biochar and investigate their characterization. This study researched the information of different biochar by some basic parameters such as yield and water absorption. The pyrolysis of wood, textile and food waste was implemented to make different biochar. Meanwhile, the temperature was different according to these materials. 500°C of pyrolysis temperature was used to make wood and food biochar and 400°C and 300°C were for wood and textile biochar. The result explained that with increasing of temperature, the yield of wood and textile biochar was reduced.

1. Introduction
In recent years, the amount of waste produced by each person has increased significantly. A normal Western Europe person is estimated to generate more than 450 kg of rubbish per year [1]. This is only for one person, a country or region may have a more obvious increase in producing rubbish. In United States, the amount of rubbish produced per year has increased by 65% since 1980 [2]. Therefore, how to manage and dispose the big amount of rubbish is an urgent problem. Municipal solid waste (MSW) generated by households is the main source of waste. The composition of MSW is complex, but some daily rubbish is the main part, such as plastics, paper, textiles and glass, wood [3]. The analysis shows that 83% of MSW are organic materials [4], so if those organic materials can be recycled, the problem of managing wastes will be alleviated instantly. Pyrolysis is a thermochemical process that organic materials can be heated at a high temperature in absence of oxygen or in an inert gas environment [5]. By pyrolysis, the organic materials that comes from MSW can become biochar, which may be used in many fields.

2. Methodology

2.1 Raw materials

2.1.1 Wood bark
The original material of wood came from Bunnings Warehouse (Sydney), the local household hardware chain. It was natural pine bark mulch whose brand was Richgro and it was aimed to reduce weed growth and retain moisture of soil. The regular size of this kind of material was 1 cm × 1 cm which was suitable to utilize in experiments. Soil and ashes were on these wood barks, so they would be washed before every experiment to keep accuracy of experimental results.
2.1.2 Cotton textile
In this study, cotton textile would be used in experiments. The raw material was from a shabby T-shirt which contained 100% natural cotton. The clothes is a white T-shirt that could avoid the influence of clothing dye to final results. Before starting, this T-shirt was washed to clean dirty things and some impurities to keep the precise of results and it would be dried. After that, it was divided into small pieces to meet the requirements of experiments and the size was 1cm × 1cm.

2.2 Pyrolysis process of wood biochar
According to Fahmi’s report [6], due to the higher ash content of hardwood, softwood may get a better productivity of bio-oil than hard wood, that means hardwood can result in more wood biochar. This is the reason why pine wood bark would be chosen as experimental material. Though those experiments, slow pyrolysis (10℃/min) was the first choice to be implemented. Because slow pyrolysis often has connections with fixed bed reactors, even if it may not meet the same requirements as fluidized bed reactor. However, fixed bed reactor can become a suitable method to dispose of wastes in industrial condition, that is the main reason fixed bed reactor was used in the experiment [7]. What is more, slow pyrolysis can have a higher yield of wood biochar than fast pyrolysis and intermediate pyrolysis. Hemicellulose in biomass completely decomposes in temperature range of 280-300 ºC [8], while cellulose decomposition is complete in the range of 300-500ºC. However, lignin in biomass was resolved over a temperature range starting around 200 ºC, extending up to 900ºC. Thus, the mass loss and reaction of wood bark happened because of those reasons. When the heating temperature reached the aimed goal, the flow rate of smoke was steady. At this time, an amount of bio-oil adhered to the glass tube.

2.3 Pyrolysis of textile biochar
100% Cotton of clothes was used into this experiment, because the main component of cotton was cellulose. Therefore, this kind of material can have almost same performance like other biomass [9]. Meanwhile, cotton is the popular material used to produce textile and clothes, that causes the main part of textile waste is cotton. Thus, cotton is a representative material used in this experiment. It was same with before experiments, slow pyrolysis and fixed bed reactors were the experimental pyrolysis and equipment. Slow pyrolysis can improve the productivity of cotton biochar and reduce the amount of bio-oil and bio-gas [10]. At the beginning of experiment, there was no reaction in the glass tube. When the heating temperature came to 250℃, light yellow smoke was released from the tube and a small amount of bio-oil adhered to the tube wall. According to Chen’s study [11], cellulose would degrade at a temperature range of 270℃-300℃, that leaded to an obvious decrease about the yield of biochar. On the other hand, cellulosic fibre may have an obvious reduction in its mass due to its lower thermal stability.

After the temperature reached the aimed goal, a steady pyrolysis stage came. During this process, the flow rate of smoke keeps consistent and the water washer became yellow because of its filtration. However, due to different pyrolysis temperature, the color of bio-oil and smoke became dark yellow with the increasing temperature. From Alper’s paper [12], two stages of decomposition of cotton fibre were happened during pyrolysis: the devolatilization stage was at 250℃-350℃ and the combustion stage was at 384℃-432℃. Higher temperature may result more substances decomposing, this is the reason why the color can change.

2.4 Tests of biochar

2.4.1 Yield
Biochar yield was calculated by the following equation:

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\text{Biochar yield (\%) = \left[\frac{\text{mass of biochar(g)}}{\text{dried mass of raw wood(g)}}\right] \times 100\%}
\]

At the first, the original dried wood would be weighed by laboratory balance and produced wood biochar was weighed as well.
2.4.2 Water absorption

According to Song and Guo’s study [13], it was a necessary property to measure the ability of remaining water by adhesion and cohesion forces. Water sorptivity of wood biochar was measured by filtration method. 10 g of dried biochar was putted into a container which contained 100 g tap water and the storing time would be 24 hours. Then a filter paper was placed on the top of container and drained the water though this filter paper until no extra water can flow from the container. After this, all immersed biochar was put on the paper. This sample would be weighed and subtracted the weight of original dry wood biochar. Finally, the water absorption was calculated by the weight of retained water divided by the initial dry weight of wood biochar and the unit was g/g of wood biochar.

Water absorption (%) = [(mass of soaked biochar - original dried biochar)/original biochar] × 100%.

3. Result and analysis

3.1 Wood biochar

3.1.1 Yield of wood biochar

Three groups of wood bark were putted into the furnace at 300 ℃, 400 ℃ and 500 ℃. The yield of wood biochar at different heating temperature was given in Figure 2. The actual wood biochar is showed in Figure 1. 

![Figure 1 400℃ biochar](image)

| Pyrolysis temperature | Mass of dried wood bark | Mass of wood biochar | Percentage of wood biochar |
|-----------------------|-------------------------|----------------------|---------------------------|
| 300 ℃                | 24.8g                   | 13g                  | 45.5%                     |
| 400 ℃                | 34.1g                   | 16.51g               | 39.4%                     |
| 500 ℃                | 32.7g                   | 10.92g               | 33.4%                     |

Figure 2 Yield of wood biochar

From Figure 1, yield of wood biochar was reduced during the process of the increased pyrolysis temperature. The percent of wood biochar were 45.5%, 39.4% and 33.4% respectively at 300 ℃, 400 ℃ and 500 ℃. According to previous report [14], because of the destruction of lignin-cellulose structure and the burning of organic materials at high temperature, experimental material will lose their mass. In Huang reported [15], that the range of 220℃-315℃ the mass of hemicelluloses would reduce and the
decomposition of cellulose happened in the next stage which was 315°C-400°C. Meanwhile, the mass of lignin decreased linearly from 160°C-900°C. Thus, higher heating temperature would destruct the structure of hemicelluloses more sufficiently and cellulose decomposed when the temperature beyond 315°C. Meanwhile, more solid material may become liquid (bio-oil) and gas (bio-gas) if the temperature met the requirement. The lossy mass of yield in this study might because of the loss of hemicelluloses and organic materials, the reduction of lignin and the conversion among solid, liquid and gas.

3.1.2 Water absorption of wood biochar

The water absorption of wood biochar at different temperature were given in Figure 4. And 500°C biochar is showed in Figure 3.

| Pyrolysis temperature | Mass of dried wood biochar | Mass of soaked wood biochar | Percentage of water absorption |
|-----------------------|---------------------------|-----------------------------|-------------------------------|
| 300°C                 | 5g                        | 8.7g                        | 23%                           |
| 400°C                 | 5g                        | 10g                         | 41%                           |
| 500°C                 | 5g                        | 12g                         | 47%                           |

Some main parts have an effect in the water sorptivity: total volume of air voids, porosity, surface functional groups and surface area. From this table, when the heating temperature improved, the water absorption also increased. According to Zhang’s study [16], the total pore volume and pore structure played an important role in water absorption. Wood biochar with larger pore volume can absorb and store more water than normal one. Meanwhile, if the pore structure of wood biochar has larger pore size, these air voids not only store more water but also act as a tunnel that can transport water to other pores effectively. Therefore, from these conclusions, higher pyrolysis temperature may increase the total pore volume of wood biochar that caused 500°C of wood biochar had a better performance in water sorptivity than the others. Meanwhile, there may be an obvious change in pore structure. Higher temperature may destruct pore structure more sufficiently and the increasing number of large pores held extra water and...
acted as a transmission to transport water to other pores.

3.2 Textile biochar

3.2.1 Yield of textile biochar

Three groups of textile biochar at different pyrolysis temperature were given in Figure 6. Textile biochar is showed in Figure 5.

| Pyrolysis temperature | Mass of textile | Mass of biochar | Percentage of biochar |
|-----------------------|-----------------|-----------------|-----------------------|
| 350℃                  | 10g             | 5.17g           | 48%                   |
| 400℃                  | 14g             | 6.32g           | 39%                   |
| 450℃                  | 10g             | 3.5g            | 31%                   |

Figure 6 Yield of textile biochar

Under this experimental condition, this result showed the factor of temperature had an obvious influence in the yield of biochar. From this table, the yield of textile biochar reduced from 48% to 31% during the pyrolysis temperature improved from 300℃ to 450℃. This decrease in biochar yield may lead to an improved devolatilization of the solid hydrocarbons in the biochar. According to Alper’s study [17], textile biochar had a higher fixed carbon than raw textile because of its higher combustion rate. The increasing fixed carbon and homogeneity, char devolatilization took place faster and easily. At the first stage, the loss of mass may due to some volatile components volatilized. This can be identified by Mohamad’s research [18], nitrogen, hydrogen and oxygen contents of biochar reduced with a rise of temperature. When the temperature improved to 380℃, combustion of biochar happened. These two parts made 450℃ of biochar lost more mass than other samples under lower temperature. On the other hand, Partial gasification of the carbonaceous residue may be another cause [19]. The first peak of mass loss may start from 302℃-456℃, a large amount of cellulose resolved during this process [20]. Meanwhile, a slight reduction of moisture content of textile biochar should also be considered.

3.2.2 Water absorption of textile biochar

The water absorption of textile biochar at three different pyrolysis temperature was given in Figure 7.
### Water absorption of textile biochar

| Pyrolysis Temperature | Mass of textile biochar | Mass of soaked textile biochar | Percentage of water absorption |
|-----------------------|-------------------------|--------------------------------|-------------------------------|
| 350°C                 | 5g                      | 12.35g                         | 47%                           |
| 400°C                 | 5g                      | 15.26g                         | 36%                           |
| 450°C                 | 5g                      | 16.22g                         | 31%                           |

Although the main component of cotton biochar is cellulose, the water absorption of cotton biochar may be different from other materials that also mainly composed of cellulose. From Figure 9, when the pyrolysis temperature improved, the ability of water absorption also went up. According to Ranjana’s study [21], a steadily release of volatile compounds happened with a rising temperature and devolatilization also happened during this process. Because of these two reasons, the biochar was more porous and the size of pore volume increased. As a result, more pores can absorb extra water than lower pyrolysis temperature of biochar. It is obvious that structural changes and surface of particles have an important influence in the ability of water absorption. From Ranjana’s paper [21], higher pyrolysis temperature changed cellulose structure and the surface of particles increased. Therefore, these factors had a positive effect in water absorption of biochar, this is the reason why higher pyrolysis temperature of biochar had a better performance in water absorption than lower ones.

### 4. Conclusion

This study explored some properties of wood and textile biochar from MSW under different pyrolysis temperature such as yield and water absorption. Some conclusions can be found from these results:

1) In slow pyrolysis of wood and textile, the biochar yield decreases when heating temperature is improving.
2) With the increasing temperature, biochar’s ability of water absorption also increases.

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