The Combustion Characteristics of Self-igniting Briquettes Prepared with Torrefied Wood Powder from a Wood-Roasting Method

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Agglomerated torrefied wood fuel was tested for its fuel properties and combustion characteristics. Torrefied wood was produced in a wood roaster, with three species (*Pinus densiflora* Siebold & Zucc., *Quercus serrata* Thumb. Ex Murray, *Sinoarundinaria nigra* var. henonis honda) that were torrefied at 220 °C for 180 s. After being torrefied, these powders were used as agglomerated torrefied wood-powder. Gelatin was used as binder, and linseed oil was spread on one side of each sample. All test samples were ignited and tested for carbon monoxide release and temperature variation. The agglomerated torrefied wood fuel showed 82% less carbon monoxide release in comparison to self-igniting briquettes. In particular, pine showed less CO release and mass loss. Also, pine and bamboo showed higher heat efficiency than the ignition coal. Therefore, using torrefied wood for agglomerated fuel reduced the carbon monoxide release and improved the heating efficiency of the ignition coal.

Keywords: Torrefaction; Carbon monoxide; Mass loss rate; Heat efficiency

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INTRODUCTION

Self-igniting charcoal briquettes are widely used as a camping fuel in Korea. Self-igniting briquettes are made of charcoal prepared from sawdust, wheat flour, barium nitrate, and sodium nitrate (SPS-KFPFA 001:2010(2010)). Charcoal is used as the main material, and charcoal is mostly made from waste wood products or wood (Hong 2008). Because waste wood contains toxic components, the raw material for ignition coal is regulated. Waste wood charcoal for ignition coal should not use waste wood from construction, preserved wood, and others. However, in an investigation of 20 different commercial self-igniting charcoal products, heavy metal components and harmful gases were found (Park 2006); the national standard does not regulate these toxic components.

Self-igniting charcoal not only has raw material problems, but also it releases much carbon monoxide during combustion. This characteristic has been used for suicide (Lee *et al*. 2014). Suicide by use of charcoal combustion has been rapidly increasing since 2008, and a solution is needed.

This study used torrefied wood generated by low temperature carbonizing (200 to 300 °C) in the absence of oxygen, which has a higher caloric value than normal wood because torrefied wood contains a higher proportion of carbon. Torrefied wood powder was used as the main component of ignition coal, with gelatin as a binder. Furthermore, this torrefied wood powder is able to take the place of illegally imported charcoal, which has an unclear background and may contain heavy metal components. Therefore, this study analyzed the new agglomerated torrefied wood charcoal combustion characteristics and harmful gas release (especially carbon monoxide).

EXPERIMENTAL

Materials

Raw materials

Domestic soft wood (pine; *Pinus densiflora* Siebod & Zucc.), hardwood (oak; *Quercus serrata* Thumb. Ex Murray), and bamboo (*Sinoarundinaria nigra* var. henonis HONDA) were used. Each of these materials was received in the form of chips from local suppliers. The average size of the chips was about 32.5 mm x 40.0 mm x 3.9 mm, and they were dried using a force blower dryer at 105 ± 30 °C for 48 h.

Torrefaction treatment

The torrefaction treatment was performed in a wood roaster (Fig. 1). This machine uses a continuous heat treatment process. The inside of the machine maintained the temperature at 200 °C to 300 °C in the absence of oxygen. Therefore, 2,000 g of each species were torrefied for 180 s. After torrefaction, samples were crushed and screened using a #8 standard screen. Material passing through the screen was used in subsequent testing. All samples were oven-dried (105 ± 3 °C, more than 48 h).

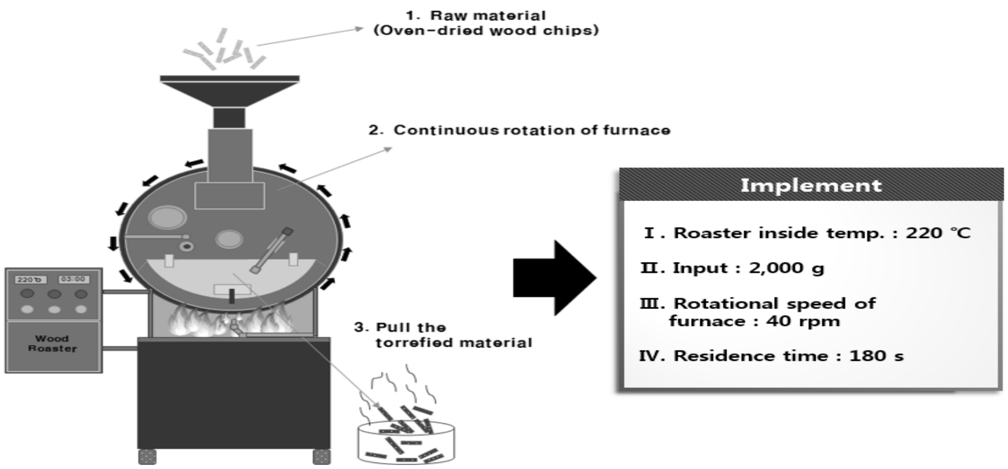

Fig. 1. Wood roaster

Binder

Pig gelatin (Chungcheon chemical, Yangju, Korea) was used for a binder, and its properties are shown in Table 1. Gelatin was mixed with distilled water at 45 ± 3 °C (water : gelatin = 2 : 1).

Table 1. Gelatin Components

Protein	Moisture	Mineral
84-90 wt.%	8-12 wt.%	2-4 wt.%

Methods

Test specimen manufacturing

Test specimens (charcoal briquettes of agglomerated torrefied wood mixtures) were made in a lab-scale 13 pin mold press (Fig. 2), and the components are shown in Table 2. Gelatin was added to 12 wt.% of dried torrefied wood powder. Each component was first mixed and then used to fill the bottom of the mold press. Then the mold press cycle was 8 kgf/cm^2 of pressure for 10 min.

Fig. 2. Mold press (lab scale)

Table 2. Experimental Ignition Coal Components

Torrefied Wood powder (TWP)	Gelatin
300 g	12 wt.% of oven-dried TWP weight

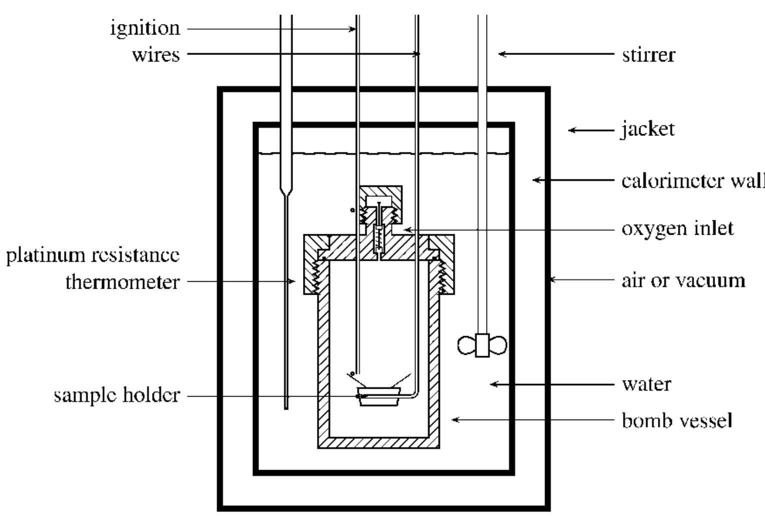

Fig. 3. Mimetic diagram of bomb-calorimeter

High calorific value (Bomb calorimeter test method)

To measure the high calorific value, a bomb calorimeter (Sundy, China) was used (Fig. 3). In this method, about 1 g samples are put in the bucket with a firing wire. The device is then filled with oxygen, using a pressure of about 25 psi. When the test is started, the sample is burned completely within the pressurized enclosure, and the heat released by the sample is absorbed by water surrounding the bomb. When the water around the bomb is constant, the heat capacity of the absorbing water and other parts in the water is constant. The calorific value can be calculated by the raised water temperature.

Combustion characteristics

A cone calorimeter test and full size test were performed to investigate combustion characteristics such as heat efficiency, mass loss rate, ignition time, carbon monoxide, and carbon dioxide release rate. For the cone calorimeter test, the specimen size was 100 mm (W) × 100 mm (L) × 10 mm (T), and the measurement output was carbon monoxide and carbon dioxide release rate and ignition time. The full size test was performed with agglomerated torrefied wood coal (Fig. 4) which had been prepared from the torrefied wood powder. Temperature variation and mass loss rate were measured as shown in Fig. 5. Temperature variation was measured by thermocouple (BTM-4208SD, LUTRON, Taiwan) at 1-min intervals.

Fig. 4. Test specimens

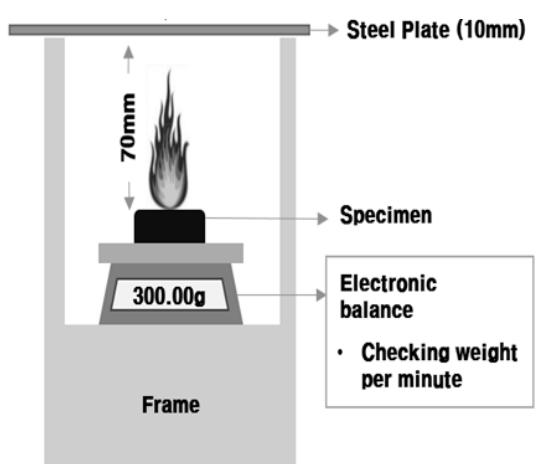

Fig. 5. Mass loss rate and temperature variation test schematic

Statistical analysis

Analysis of variance (ANOVA) was conducted ($p < 0.05$) to evaluate the difference between each type of specimen. Significant differences among the average of cone calorimeter test results of each type of specimen were observed using Duncan's new multiple range test (Duncan test). The Duncan test was run to compare each type of specimens' high heating value, ignition time, total heat release rate, carbon monoxide, and carbon dioxide release in search of significant interactions.

RESULTS AND DISCUSSION

High Heating Value

Figure 6 shows a plot of the higher heating value for complete combustion of three different species and different treatment types. The average value of torrefied wood powder was 5,320 cal/g, which was about 11% higher than non-treated wood (4,675 cal/g); notably, torrefied pine was 13% higher. This result reflects that higher resin content leads to higher caloric value than lower resin content (Corder 1975). The commercially available self-igniting charcoal product showed a value of 4,319 cal/g because it contained barium nitrate and sodium nitrate, which are combustion retardants. The commercial product showed incomplete combustion because of these chemicals.

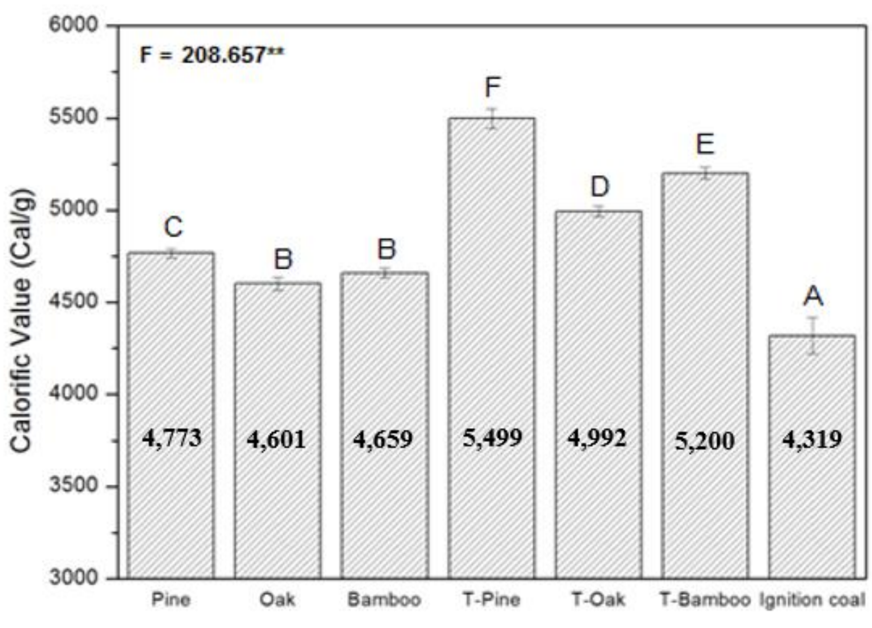

Fig. 6. Comparison of high heating values between the control and each specimen

Combustion Characteristics

Cone calorimeter test

Table 3 shows the results of ignition tests for the torrefied wood powder and the commercially available self-igniting charcoal briquettes. The product prepared from the torrefied wood powder showed 65% faster ignition time than the commercial product. The total heat release (THR) was affected by organic material volatile matter content; charcoal has lower heat release than wood because it has flameless combustion (Shin 2005). Also, carbon monoxide release was tested for 5 min, and the results are shown in Fig. 7. Around 150 to 175 °C, carbon monoxide release was increased in all test specimens, especially the commercially available self-igniting charcoal briquettes. Torrefied wood powder released about 50 ppm of carbon monoxide; however, the commercial product exhibited a 400% higher carbon monoxide release. Therefore, torrefied wood powder could be considered as solid fuel because devolatilized organic volatile matter torrefied wood powder exhibited faster ignition time, higher heat release, and less carbon monoxide release.

Table 3. Results of Con-Calorimeter Experiment

Content	Cone Calorimeter Experiment							
	Ignition time (sec) $F = 45.316^{**}$		THR (MJ/kg) $F = 160.861^{**}$		CO_2 (%) $F = 50.222^{**}$		CO (ppm) $F = 163.128^{**}$	
	Mean ± SD	DT	Mean ± SD	DT	Mean ± SD	DT	Mean ± SD	DT
T-Pine	28 ± 3	B	25.53 ± 0.38	C	0.15 ± 0.01	B	5,967 ± 236	A
T-Oak	34 ± 2	B	23.1 ± 0.36	BC	0.16 ± 0.01	B	5,880 ± 439	A
T-Bamboo	15 ± 3	A	22.06 ± 0.76	B	0.14 ± 0.01	B	5,731 ± 339	A
Ignition coal	68 ± 10	C	9.4 ± 0.66	A	0.08 ± 0.01	A	25,650 ± 2,495	B

- THR : Total Heat Release
- DT : Duncan's new Multiple range test

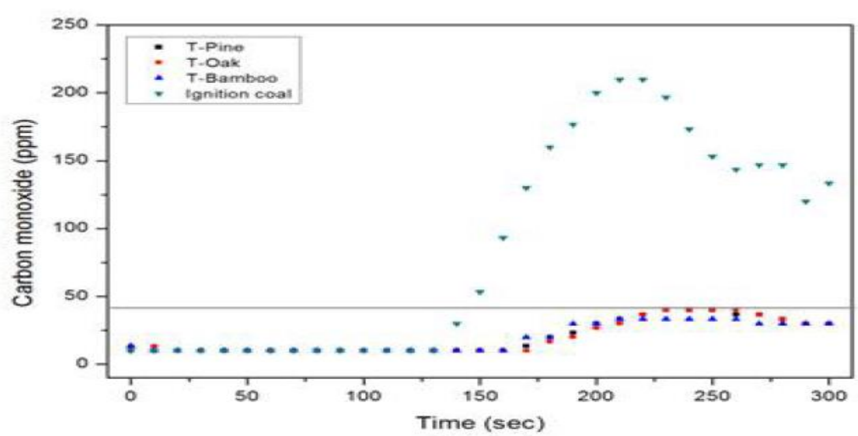

Fig. 7. Comparison of CO emission between torrefied specimens and the Ignition coal

Full size test (mass loss rate)

Figure 8 shows the mass loss rate of full size test specimens. Briquettes prepared from torrefied pine showed the lowest mass loss rate, and they had the highest final residual rate (26.6%). Bamboo yielded 22.7% and oak yielded 12.3%. This result may reflect the fact that pine is the lowest density material, and bamboo had the smallest particle size of the tested materials.

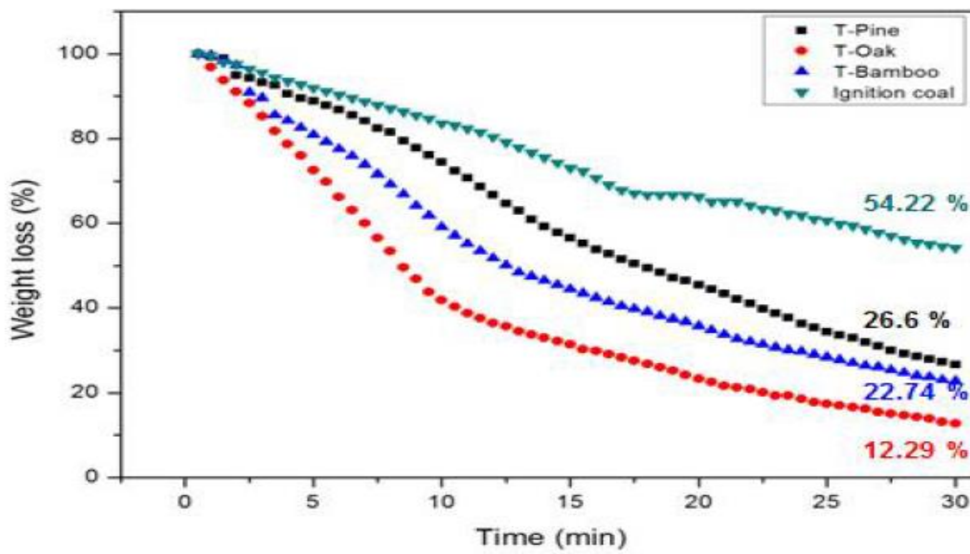

Fig. 8. Comparison of weight loss between torrefied specimens and the ignition coal

Full size test (temperature variation)

Figure 9 shows the result of temperature variation of full-size specimens of briquettes prepared from torrefied material from each species of wood or bamboo. Between 5 and 15 min, all specimens showed the highest temperature, and agglomerated torrefied briquettes exhibited a higher temperature than the commercially available charcoal briquettes. Especially, briquettes made from torrefied pine and bamboo had a higher value than the others because these materials have low density and small particle size. Therefore, the briquettes made from torrefied pine and bamboo exhibited better fuel characteristics than the commercially available briquette product.

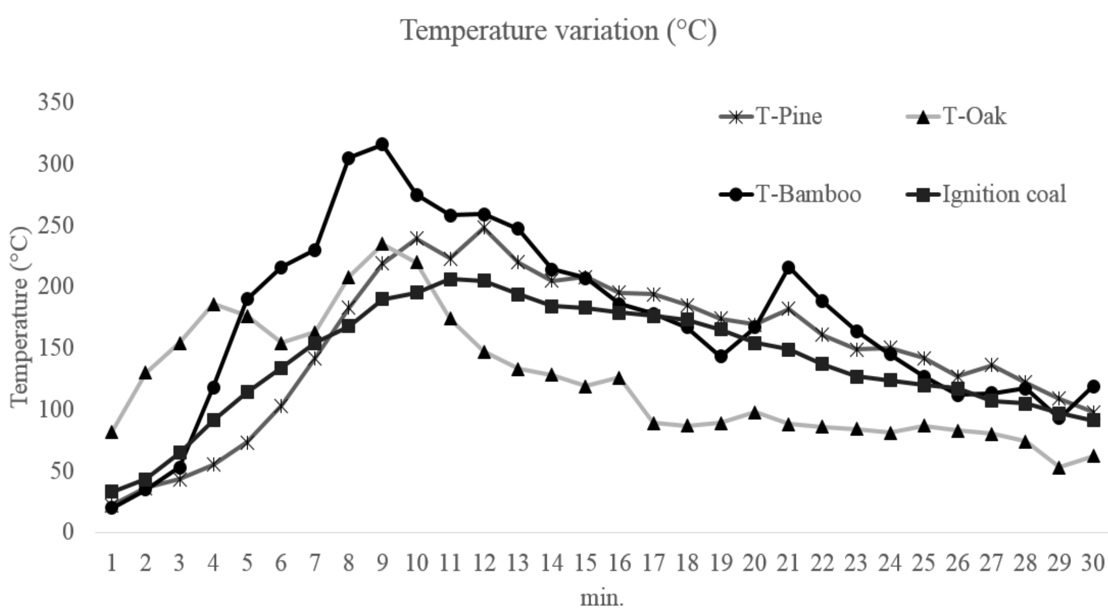

Fig. 9. Comparison of temperature variation between torrefied specimens and the commercially available charcoal briquettes

CONCLUSIONS

1. All torrefied wood powder had higher caloric values than non-treated wood powder and the commercially available charcoal briquettes that were used for comparison.
2. Torrefied wood powder had a faster ignition time and higher heat release than the commercial product because of its volatile content.
3. The carbon monoxide release of the torrefied specimens was around 23% of the commercial charcoal briquettes.
4. Using torrefied wood powder for agglomerated coal reduced carbon monoxide release, and it improved fuel characteristics (ignition time, heat release, *etc*.).

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