The Manufacturing Process Of Bamboo Pellets

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Abstract

Bamboo was a kind of biomass materials and had great potential as a bio-energy resource of the future in China. The physical and combustion properties of bamboo pellets were determined and the effects of moisture content (MC) and sizes of particle on these properties were investigated in this research. The results showed that MC and sizes of particle affected these properties of bamboo pellets. The effects of MC on physical properties including length, diameter, pellet MC, unit density, bulk density were significant at $p=0.05$. But there were not significantly difference between particle size (PS) and all properties of bamboo pellets. The optimum manufacturing process was 16% MC and PS mixture. All properties of bamboo pellets could meet the requirement of *Pellets Fuel Institute Standard Specification for Residential/Commercial Densified* and the gross calorific value could also meet the minimum requirement for making commercial pellets of DIN 51731 (>17500J/g), respectively. Bamboo pellets would be the proposed new biomass solid fuel and had the potential to be development as commercial pellets.

Key words: Biomass, Bio-energy, Bamboo, Bamboo pellet, Physical property

1. Introduction

There were several alternative energy which could substitute fossil fuel in the future, such as hydro, solar, wind, biomass and ocean thermal energy. Among these energy sources, biomass was the only carbon-based sustainable energy and the wide variety of biomass enabled it to be utilized by most people around the world (Faizal et al., 2010). Bamboo was a kind of biomass materials and had been widely cultivated in the west and south of China. Currently, bamboo resource was very abundant and the total area of bamboo was about five million hectares and that of moso bamboo *(Phyllostachys heterocycla)* was about 3 million hectares in China (Jiang, 2002). Annual yield of moso bamboo was about eighteen million tons, which was widely used to produce furniture, flooring and interior decoration materials. Bamboo, like wood, was mainly composited of hemicelluloses, cellulose and lignin. It had great potential as a bio-energy resource of the future in China.

The biomass pellets and briquettes were a main kind of bio-energy and they had better flow properties. Densification into pellets could reduce material wastage and improve ease of transporting and storage (Adapa et al., 2006). In the recent years, various pellets had been studied such as biomass waste materials (Ayhan and Ayse, 2004), spring-harvested reed canary-grass (Susanne and Nilsson, 2001), switchgrass (Colley et al., 2006), cotton stalk (Abasaeed, 1992), peanut hulls (Fasina and Sokhansanj, 1993), poultry litter (Mcmullen et al., 2004), corn-soybean (Parsons et al., 2006). During the densification process of biomass pellets, the MC and PS of materials were considered as two main factors affected to properties of pellets. Faizal et al. (2009) studied the physical characteristics of briquette contains different mixing ratio of empty fruit bunch fiber and mesocarp fiber. Holt et al. (2006) manufactured fuel pellets using by-products from two cotton gins. The treatments resulted from using different material streams from the ginning process as well as varying quantities of starch and/or crude cottonseed oil during the fuel pellet manufacturing process. The fuel pellet density from the various treatments ranged from 488 to 678 kg/m3. Zimonja and Svihus (2009) conducted to investigate the influence of cereal starch exposed to various processing techniques on physical pellet quality and nutritional value of the diets fed to broiler chickens. The combustion properties of pellets were one of main characteristics for solid fuel. Susanne and Calle (2001) investigated ash problems of spring-harvested reed canary-grass briquettes during the combustion. Ann and Petersen (2006) studied how much greenhouse gas (GHG) was emitted for various kinds of fuel wood, sawdust, pellets, briquettes, demolition wood, and bark (not only CO_2, but also CH_4 and N_2O). Maria (2010) determined the emissions of organic compounds from incomplete burning of oats using gas chromatography and compared to those of softwood pellets. The use of coal-biomass briquettes will effectively reduce the indoor concentration of sulfur dioxide (SO2) emitted during raw coal combustion. Indoor concentrations of SO2 emitted from combustion of either coal-biomass briquettes or low-grade coal in households were measured and were found to be less with coal-biomass briquettes (Yugo et al., 2005). Telmo and Lousada (2011) tested the calorific values of wood pellets from different wood species using a Parr 6300 bomb calorimeter, and softwoods had a high calorific value between 19660.02 and 20360.45kJ/kg, but the hardwoods had a ranging interval between 17631.66 and 20809.47 kJ/kg.

All briquettes prepared from mango leaves, eucalyptus leaves, wheat straw, and saw dust had more heating value than the half of the Indian coal and these could be used as an alternative for the coal and also for fire wood (Varun et al., 2010).

To date, no information was available about bamboo pellets. This study was therefore carried out to determine properties of bamboo pellets, which was manufactured using different MC and PS of bamboo. The purpose of this research analyzed the effect of MC and PS on physical properties of bamboo pellets and provided guidelines for later research.

2. Materials and methods

2.1 Materials

Maso Bamboo was used in the study. The initial MC of samples was about 6.13%, their density was about 0.65g/cm^3. Bamboo materials were cut off to sample size 40mm (longitudinal) by 3-8mm (radial) by 20-30mm (tangential). Then, they were broken down to particles using wood particle

mill at Forestry Products Laboratory of USDA Forest Service. Finally, they were screened to get three different kinds of bamboo PS.

2.2 Pellet Formation

The bamboo pellets were manufactured using laboratory pellet mill (L-175), made by AMANDUS KAHL NACHE HAMBURG COMPANY. The effects of MC and PS of bamboo were carried out at by a 3^2 full-factorials design shown in Table 1. The manufacturing processes were shown:

1. The bamboo particles were separated according their PS. Three kinds of PS, used in the study, were respectively PS1 (the particle diameter was more than 1.18mm), PS2 (the particle diameter was 1.18-0.84mm) and PS3 (the particle diameter was less than 0.84mm).
2. One kilogram (1kg) of bamboo particles with PS1, PS2 and PS3 were respectively put into the conditioning room with temperature 27℃, humidity 65% and temperature 27℃, humidity 90% to adjust their MC to about 8%, 12% and 16%. For the highest MC (16%), bamboo particles were conditioned by adding predetermined amounts of distilled water onto the samples.
3. The bamboo particles were transferred to separate Ziploc bags and sealed tightly. Then they were kept in a conditioning room (temperature 27℃, humidity 65%) for 48h to enable moisture to be distributed uniformly.
4. MC of bamboo particles was tested using drying oven at 105℃ for 8h. The initial and final mass was measured by a digital balance. MC of bamboo particles was calculated basis on the mass loss.
5. The parameters of pellet mill were set to rotary speed 235r/min and pellets diameter 5.9mm.

6. The bamboo particles were continuously feed into pellet mill, and bamboo pellets were formatted.
7. The bamboo pellets were collected and were kept in the laboratory more than a week, and then their properties were tested.

Table 1 Experimental design

Experiment No.	MC (%)	PS (mm)
1	8	PS1
2	8	PS2
3	8	PS3
4	12	PS1
5	12	PS2
6	12	PS3
7	16	PS1
8	16	PS2
9	16	PS3

2.3 Properties Test

(1) Pellet dimension

The pellets were cylindrical in the shape. In order to determine dimensions and unit mass, ten bamboo pellets were randomly selected in each experiment. The length (L) and diameter (d) of every sample were measured using a digital vernier caliper. The mass of bamboo pellets (m) was weighted using a precision digital balance (0.0001 Resolution).

(2) Unit density (ρ_u)

Unit density of bamboo pellets were determined by weighting the individual pellet and calculating its volume basis on its length and diameter as per the following equations.

$$V_u = \pi/4d^2L \tag{1}$$

$$\rho_u = m_u/V_u \tag{2}$$

Where, V_u was the volume of individual pellet, cm^3; d was the diameter of pellet, mm; L was the length of pellet, mm; ρ_u was the unit density, g/cm^3; m_u was the mass of individual pellet, g.

(3) Bulk density (ρ_b)

Bulk densities were calculated as the ratio of the mass of materials to the volume of the container. The bamboo pellets were leveled with the top surface of the container and they were weighed using a precision digital balance (0.0001 Resolution). The volume of container was calculated by measuring its length and diameter.

$$P_b = m_b/V_b \tag{3}$$

Where, ρ_b was the bulk density, g/cm^3; V_b was the volume of cintainer, cm^3; m_b was the total mass of pellets, g.

(4) Pellet MC

Pellet MC was determined by mass loss of samples. Ten bamboo pellets in every process were heated using drying oven under rigidly controlled conditions of temperature (105℃), time (8h). Then they were removed from drying oven and put into a desiccator to cool to room temperature. The next, they were weighted using a precision digital balance (0.0001 Resolution). Samples were returned to drying oven at 105℃ for 2h and they were cooled and weighted. When mass varies of samples was less than 0.2%, their final mass was recorded. MC was calculated using the following equation:

$$MC = (m_i - m_f)/m_f \times 100\% \quad (4)$$

Where, MC was pellet moisture content (%), m_i was initial mass of samples (g), and m_f was final mass of samples (g).

(5) Pellet fine (P_f)

Pellet fine was determined using 3.17mm (1/8in) wire screen sieve according to *Pellets Fuel*

Institute Standard Specification for Residential/Commercial Densified. Fifty bamboo pellets were randomly selected and were divided into ten groups. The initial mass of every group sample was weighted using a precision digital balance (0.0001 Resolution). They were placed on wire screen sieve and tilted it from side to side ten times. Then the final mass was weighted and recorded. The pellet fine was calculated using the following equation:

$$P_f = (m_i - m_f)/m_i \times 100\% \quad (6)$$

Where, P_f was fine of samples (%), m_i was initial mass of samples (g), and m_f was final mass of samples (g).

(6) Pellet durability (P_d)

Pellet durability was determined by mass loss of samples. Fifty bamboo pellets in every process were randomly selected and weighted using a precision digital balance (0.0001 Resolution). The initial mass was recorded. Then they were put into a vibrating sieve with screen size 3.17mm (1/8in). After ten minutes, they were weighted again and the final mass was recorded. The pellet durability was calculated using the following equation:

$$P_d = 100 - (m_i - m_f)/m_i \times 100\% \quad (5)$$

Where, P_d was pellet durability index (%), m_i was initial mass of samples (g), and m_f was final mass of samples (g).

(7) Pellet absorption (P_a)

Pellet absorption was determined through mass change of samples. Five bamboo pellets in every process were randomly selected. They were dried at temperature 105℃ until their mass did not change and then the initial mass of samples was weighted using a precision digital balance (0.0001 Resolution). They were kept in the conditioning room (temperature 27℃, humidity 90%) for 24h. Then the final mass of samples was weighted and recorded. The pellet absorption was calculated using the following equation:

$$P_a = (m_i-m_f)/m_i \times 100\% \qquad (7)$$

Where, P_a was absorption of samples (%), m_i was initial mass of samples (g), and m_f was final mass of samples (g).

(8) Inorganic ash (Ia)

Inorganic ash of bamboo pellets were determined basis on the percent inorganic material in the bamboo pellets.

1. Five empty crucibles were ignited in the muffle furnace at 600℃, were cooled in the

   desiccator and were weighted using a precision digital balance (0.0001 Resolution).
2. About 2g bamboo pellets were placed in every crucibles, were determined the weight of crucibles plus bamboo pellets and were placed in the drying oven at 105℃. After 2 h, they were replaced, were cooled in the desiccator to room temperature and were weighted.
3. The crucibles were returned to drying oven at 105℃ for 2h and were cooled and weighted. When weight variance of the crucible was less than 0.2%, the final weight was recorded.
4. The crucibles were placed in the muffle furnace at 600℃ and were ignited until all the carbon was eliminated.
5. The crucibles were removed from muffle furnace and were cooled in the desiccator and weighted using a precision digital balance (0.0001 Resolution).
6. Inorganic ash content was calculated basis on the following equation.

$$Ia = (W_1/W_2) \times 100\% \qquad (8)$$

Where, Ia was inorganic ash content, %; W_1 was weight of inorganic ash, g; and W_2 was weight of oven-dry bamboo pellets, g.

(9) Gross calorific value (Gc)

The gross calorific value was the amount of energy per unit mass released upon complete combustion. The calorific value of bamboo pellets was tested using *PARR 1266 Bomb Calorimeter*.

Before testing gross calorific value of bamboo pellets, the calorimeter was calibrated with tablets of benzoid acid whose calorific value was 26465 J/g. In this test, about 1g bamboo pellets was introduced in the bomb, which was charged slowly with pure oxygen (>99.95 vol. %, quality 3.5) to a pressure of 3.0±0.2 MPa without displacing the original air. Any combustion aid was not used and five samples were tested in every condition. The final experimental result was the average value of five samples.

(10) Combustion rate (Cr) and Heat release rate (Hr)

The fire time was recorded according to *PARR 1266 Bomb Calorimeter.* It was time for bamboo pellets combustion was completed. Basis on the amount of total bamboo pellets and fire time, the average combustion rate could be calculated by using following equation.

$$Cr = M/t \qquad (9)$$

Where, Cr was the average combustion rate, g/s; M was the mass of bamboo pellets, g; t was fire time in every test, s.

By knowing the gross calorific value and average combustion rate, the heat release rate could be calculated by using following equation (Faizal et al, 2010).

$$Hr = Gc \times Cr \qquad (10)$$

Where, Hr was the heat release rate, J/s; and Cr was the average combustion rate, g/s.

2. Results and discussions

2.1 Effects of MC on properties of bamboo pellets

Table 2 showed the effects of MC on some physical properties of bamboo pellets. For every physical property, the data presented were the mean of measurements made on 30 pellets at each MC level. As shown in Table 2, the mean length of bamboo pellets ranged between 12.71mm and 11.69mm. The length values were 12.50mm, 12.71mm and 11.69mm at 8%, 12% and 16% MC levels, respectively. The length of the pellets affected the fuel feeding properties. The shorter the pellets, the easier the continuous flow could be arranged (Paivi, 2001). The mean diameter of bamboo pellets slightly ranged and the values were respectively 6.086mm, 6.036mm and 6.044mm at 8%, 12% and 16% MC level. The dimensions of pellets, both diameter and length, were important factors with respect to combustion. Experience had shown that thinner pellets allowed a more uniform combustion rate than thicker ones, especially in small furnaces (Paivi, 2001). The mean mass value was biggest at 12% MC level, the next was 16% and the last was 8%. The absorption of bamboo pellets also slightly ranged at each MC level. The difference could result from different pore structure of bamboo pellets when they were manufactured using bamboo particles with different MC levels. The pellet MC slightly increased with increase in particle MC. According to Table 2, the unit density and bulk density values were 1.05g/cm^3, 1.14g/cm^3, 1.20 g/cm^3 and 0.522 g/cm^3, 0.625 g/cm^3, 0.652 g/cm^3 at 8%, 12% and 16% particle MC, respectively. The unit density and bulk density of bamboo pellets were increased with increase in particle MC. Transport efficiency depended on the bulk density of pellets. The strength of pellets was also an important factor connected with handling and transporting. In the research, the strength of pellets included two parameters, durability and fine. Table 2 showed the change of durability and fine of bamboo pellets. The pellet durability increased with increase in particle MC and the values were respectively 95.07%, 97.95% and 98.38%. For pellet fine, however, the smallest value was 16% MC level, the next was 8% and the last was 12%. The unit density was a very important parameter affected the durability and fine of pellets. The unit density of bamboo pellets were increased with increase in particle MC. The bigger the unit density, the higher was durability of pellets and the less was fines of pellets.

Table 3 showed the effects of MC on combustion properties of bamboo pellets. As shown in Table 3, the inorganic ash of bamboo pellets slightly ranged between 1.46% and 1.34%, and the values were 1.46%, 1.38% and 1.34% at 8%, 12% and 16% MC levels, respectively. The proportion of organic material decreased during the formation process of bamboo pellets (Paivi, 2001), which led to the difference of inorganic ash of bamboo pellets. For 16% MC, bamboo pellets were easier formatted in the manufacturing process and the reduction of organic materials was less, which resulted in a minimum inorganic ash content of bamboo pellets. There were no significant difference of gross calorific value of bamboo pellets manufactured using different MC. The slight variance of gross calorific value was due to the heat energy required to vaporize water because of hydrogen released during combustion process of bamboo pellets. The bamboo pellets made of different MC had different combustion rate. The combustion rate for bamboo pellets increased as MC increased from 8% to 16% MC. This was because when MC increased, the dwell time of bamboo particles in the die set was shorter and the air gap between particles of bamboo pellets was also more. Due to better air circulation through the air gap of pellets, the combustion rate of pellets increased (Faizal et al, 2010). In this research, the combustion rate of bamboo pellets manufactured by 16% MC was highest, the next was 12% and the last was 8%. It was also found that the heat release rate of bamboo pellets was also increased with MC increase. The main reason was that combustion rate increased with MC increase even though the gross calorific value seemed to be constant. The value of heat release rate were respectively 3164J/s, 3307J/s and 3377J/s for the 8%, 12% and 16% MC.

In sum, the properties of bamboo pellets, including physical properties (length, diameter, mass, pellet MC, absorption, unit density, bulk density, porosity, durability and fine) and combustion properties (inorganic ash, gross calorific value, combustion rate and heat release rate) were tested. The particle MC affected these properties and analysis of variance results (Table 4) showed that the effects of particle MC on length, diameter, pellet MC, unit density, bulk density were significantly different at p=0.05.

Table 2 Physical properties of bamboo pellets manufactured by different MC particles

MC (%)	L (mm)	d (mm)	Mass (g)	Pellet MC (%)	Pa (%)	ρ_u (g/cm^3)	ρ_b (g/cm^3)	Pf (%)	Pd (%)
8	12.50	6.086	0.3827	4.91	11.12	1.05	0.522	0.41	95.07
12	12.71	6.036	0.4140	4.96	11.35	1.14	0.625	0.54	97.95
16	11.69	6.044	0.3975	5.35	10.95	1.20	0.652	0.27	98.38

Table 3 Combustion properties of bamboo pellets manufactured by different MC particles

MC (%)	Ia (%)	Gc (J/g)	Cr (g/s)	Hr (J/s)
8	1.46	18465.90	0.171	3164.62
12	1.37	18438.78	0.179	3307.79
16	1.34	18457.46	0.183	3377.81

Table 4 Analysis of variance

Properties	Variance	SS	df	MS	F value	P-value	F crit
	Interior-group	21.40	2	10.70	3.69	0.0287103	3.10
Length	Inter-group	251.65	87	2.89			
	Total	273.06	89				
	Interior-group	0.043	2	0.02	16.66	7.471E-07	3.10
Diameter	Inter-group	0.11	87	0.0012			
	Total	0.15	89				
	Interior-group	3.50	2	1.75	5.22	0.0072033	3.10
Pellet MC	Inter-group	29.22	87	0.33			
	Total	32.72	89				
	Interior-group	0.32	2	0.16	11.35	4.16E-05	3.10
Unit density	Inter-group	1.25	87	0.014			
	Total	1.57	89				
	Interior-group	0.28	2	0.14	175.08	3.167E-31	3.10
Bulk density	Inter-group	0.07	87	0.0008			
	Total	0.35	89				

2.2 *Effects of PS on the properties*

Table 5 showed the effects of PS on physical properties of bamboo pellets. As shown in Table 5, the mean length of bamboo pellets decreased with increase in PS and the values were 12.62mm, 12.24mm and 11.94mm at PS1, PS2 and PS3 levels, respectively. The mean diameter and mass of bamboo pellets slightly ranged and the values were respectively 6.052mm, 6.062mm 6.053mm and 0.4006g, 0.3975g, 0.3961g. The pellet absorption also slightly ranged at three PS levels. The variance could result from different pore structure of bamboo pellets and surface/volume ratio of bamboo particles. When water dripped to pellet surface, absorption, spreading and permeability happened at the same time. The pore structure of bamboo pellets affected removing process of water.

The inter-porosity of bamboo pellets, made of PS1, was bigger and more than that of other bamboo pellet, made of PS2 or PS3. The variance of inter-porosity resulted in the difference of surface/volume ratio in the inner of bamboo pellets. High surface/volume ratio in each particle allowed better penetration of moisture. Link et al. (1999) found linear relationship between the absorption maximum of the longitudinal plasmon resonance and the mean surface/volume ratio as determined from TEM. The absorption of bamboo particle was also different for PS1, PS2 and PS3. Barltrop and Meek (1979) found an inverse relationship between particle size and absorption of lead. So particle absorption should be biggest for PS3, the next was PS2 and the last was PS1 in this research. Li et al. (2010) found that water absorption of rice straw particleboard increased with decrease in PS. According to Table 5, the unit density and bulk density values were 1.11g/cm^3, 1.13g/cm^3, 1.16 g/cm^3 and 0.599 g/cm^3, 0.600 g/cm^3, 0.600 g/cm^3 at PS1, PS2, PS3 levels, respectively. The unit density and bulk density of bamboo pellets were increased with increase in PS. The pellet durability increased with increase in PS and the values were respectively 97.96%, 97.21% and 96.23%. For pellet fine, however, the smallest value was bamboo pellets, made of PS1, the next was PS2 and the last was PS3. The smaller particle size made the feedstock slippery and it slid through the holes too easily, thereby reducing pellet strength.

Table 6 showed the combustion properties of bamboo pellets. As shown in Table 6, the inorganic ash of bamboo pellets decreased with the PS increase and the value was 1.45%, 1.38% and 1.32% for PS1, PS2 and PS3, respectively. There were no significant difference of gross calorific value of bamboo pellets manufactured using different PS. The gross calorific value of bamboo pellets was respectively 18463J/g, 18464J/g and 18434J/g. The gross calorific value of all bamboo pellets could meet the minimum requirement for making commercial pellets (>17500J/g), as stated by DIN 51731 (Faizal et al, 2010). The bamboo pellets made of different PS had different combustion rate. The combustion rate for bamboo pellets increased as PS increased. Air circulation affected the combustion rate of pellets when they were burned (Faizal et al, 2010). The bigger PS of bamboo material, the more inner porosity of bamboo pellets, which could led to a better air circulation in the combustion process of bamboo pellets. It was also found that the heat release rate of bamboo pellets was also increased with PS increase even though the variance was no significant. The value of heat release rate were respectively 3271J/s, 3277J/s and 3301J/s for PS1, PS2 and PS3. It came to an experimental conclusion that the combustion process of bamboo pellets manufactured by PS3 was the best, which also proved why its inorganic ash was the lowest in this research.

In sum, the effects of PS on some properties of bamboo pellets were investigated in this research. The PS affected the properties of bamboo pellets, but the variance of these properties was not significant at p=0.05 basis on analysis of variance method.

Table 5 Physical properties of bamboo pellets manufactured by particles with different sizes

PS	L (mm)	d (mm)	Mass (g)	Pellet MC (%)	Pa (%)	ρ_u (g/cm^3)	ρ_b (g/cm^3)	Pf (%)	Pd (%)
PS1	12.62	6.052	0.4006	5.06	11.31	1.11	0.599	0.27	97.96
PS2	12.24	6.062	0.3975	5.20	11.32	1.13	0.600	0.46	97.21

PS3	11.94	6.053	0.3961	4.96	10.79	1.16	0.600	0.49	96.23

Table 6 Combustion properties of bamboo pellets manufactured by particles with different sizes

PS	Ia (%)	Gc (J/g)	Cr (g/s)	Hr (J/s)
PS1	1.45	18463.07	0.177	3271.62
PS2	1.39	18464.22	0.177	3277.22
PS3	1.33	18434.85	0.179	3301.39

2.3 The optimum manufacturing process

The density of pellets was very important to evaluate product properties. Several national standards described the particle density of pellets and briquettes as a quality indicator of densified fuels. The maximum throughout for such a large-scale biomass bulk terminal was set at 40 tons per annum, both solid and liquid biomass, which implied that substantial storage facilities and spaces and handing systems were required. Transport and handing efficiency and amount of storage space depended on the bulk density of pellets. The increase of bulk density reduced the amount of storage space. So in this research, the bulk density was selected to optimize the manufacturing process of bamboo pellets. Table 7 showed the bulk density of bamboo pellets with different MC and PS. According to Table 7, the bulk density values were 0.522 g/cm^3, 0.625 g/cm^3, 0.652 g/cm^3 at 8%, 12% and 16% particle MC, respectively. But for different PS, the bulk density value was very slightly various. Analysis of variance results (Table 8) showed that the effects of MC on bulk density were significantly different and the variance between bulk density and PS was not significant at p=0.05. So the optimum MC was 16%, and Mixture or any kind of PS, used in this research, was selected to manufacture bamboo pellets. The bamboo pellets photo, made in the optimum process, was shown in Figure 1.

Table 7 The bulk density of bamboo pellets with different MC and PS

Process parameters	MC (%)			PS		
	8	12	16	PS1	PS2	PS3
ρ_b	0.522	0.625	0.652	0.599	0.600	0.600

Table 8 Analysis of variance

Process parameters	Variance	SS	df	MS	F value	P-value	F crit
MC	Interior-group	0.28	2	0.14	175.08	3.167E-31	3.10
	Inter-group	0.07	87	0.0008			
	Total	0.35	89				
PS	Interior-group	4.894E-05	2	2.447E-05	0.0060462	0.99	3.10
	Inter-group	0.3521291	87	0.0040475			
	Total	0.3521781	89				

Figure 1 The bamboo pellets with 16% MC and PS mixture

3 Conclusions

It could be concluded from this research that MC and PS affected the properties of bamboo pellets. The effects of MC on some properties such as length, diameter, pellet MC, unit density, bulk density were significant at p=0.05. But there were not significantly difference between PS and all properties of bamboo pellets. The optimum manufacturing process was 16% MC and PS mixture in this research. All properties of bamboo pellets could meet the requirement of *Pellets Fuel Institute Standard Specification for Residential/Commercial Densified*. The gross calorific value of bamboo pellets could also meet the minimum requirement for making commercial pellets of DIN 51731 (>17500J/g), respectively. The experimental result showed that bamboo pellets would be the proposed new biomass solid fuel and had the potential to be development as commercial pellets.

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