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PHYSICAL, MECHANICAL AND ENERGETIC PROPERTIES OF *Tachigali chrysophylla* UNDER DIFFERENTS FINAL CARBONIZATION TEMPERATURES[1]

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Abstract

The charcoal production from wood wastes is a viable and suitable alternative to income Amazon region. However, it is necessary to define the best parameters for the optimization of production. The aim was to study the effect of three final temperatures (300, 400 and 500ºC) in physical, mechanical and energetic properties of wood waste charcoal of *Tachigali chrysophylla*. The material was collected in an area under second cutting cycle forest management in the Amazon. Branch waste of three trees were cut in 20x20x40mm³ samples and carbonized at different final temperatures at 1.6°C.min^{-1}. The apparent density, mechanical strength and modulus of elasticity at parallel compression, gravimetric yield on charcoal and the higher heating value were determined. The data were analyzed with $p<0.05$. The final temperature affected the evaluated charcoal properties . The temperature of 500ºC is indicated when a charcoal with high mechanical strength at parallel compression and higher heating value is aimed. When the objective are higher apparent density and gravimetric yield in charcoal, the final temperature of 300ºC should be used.

Keywords: Amazonian waste, Charcoal, High Heating Value.

PROPRIEDADES FÍSICAS, MECÂNICAS E ENERGÉTICAS DE *Tachigali chrysophylla* SOB DIFERENTES TEMPERATURAS FINAIS DE CARBONIZAÇÃO

Resumo

A produção de carvão a partir de resíduos é uma alternativa viável e sustentável para o desenvolvimento da região amazônica. Entretanto, é preciso definir os melhores parâmetros para otimização da produção. O objetivo aqui foi estudar o efeito de três temperaturas finais (300, 400 e 500ºC) nas propriedades físicas, mecânicas e energéticas mais relevantes para produção de carvão vegetal de resíduos de madeira de *Tachigali chrysophylla*. O material utilizado neste estudo foi coletado em área sob segundo ciclo de manejo florestal na Amazônia Oriental. Resíduos de galho de três árvores foram seccionados em amostras de 20x20x40mm³ e carbonizados a 1,6°C.min^{-1}. Foram determinadas a densidade aparente, resistência mecânica e módulo de elasticidade à compressão paralela, rendimento gravimétrico e poder calorífico superior do carvão vegetal. Os dados foram analisados com $p<0,05$. A temperatura final de carbonização afetou as características do carvão avaliado. A temperatura de 500ºC é indicada quando se visa carvão de alto poder calorífico superior e resistência mecânica à compressão paralela. Quando o objetivo é maior densidade aparente e rendimento gravimétrico em carvão deve-se utilizar temperatura final de 300ºC.

Palavras-chave: Resíduos amazônicos, Carvão vegetal, Poder Calorífico Superior.

INTRODUCTION

Studies realized in the state of Para, Brazil showed that approximately 0.4m³, in the shape of residues above 20 centimeters of diameter, are left in the forest for each 1m³ of harvested log (SILVA-RIBEIRO et al., 2016; KERN et al., 2010). Gomes and Sampaio (2004) estimates that only about 40% to 60% of the total log volume is used in primary processing units, with residues being stored without proper destination.

Brazil is the largest producer of charcoal in the world with 5.5 million tons in 2016, using it mainly in steel industry and, in lower proportions, for domestic purposes (FAO, 2018; NEVES et al., 2011). The largest part of this production comes from the *Eucalyptus* plantations, however, in Amazon this reality is still distant. Thus, it is necessary to characterize energetically the available residues, maximizing their use and subsidizing the knowledge of species for genetic improvement of future plantations, besides the possibility of generating income for the local economy.

Among the factors, which affect the charcoal quality, the final temperature plays a fundamental role, as observed by Oliveira et al., (2010). These authors also evidence that the analysis of different final carbonization temperatures may help in the evaluation of wood behavior in carbonization process, improving the charcoal properties for each purpose.

In this context, it was aimed to evaluate if the final temperature affects, significantly, some characteristics of *Tachigali chrysophylla* charcoal and if there is an ideal temperature to optimize the charcoal production of these residues.

MATERIALS AND METHODS

Wood residues of an area under second cutting cycle forest management in Tapajos National Forest Tapajos, Belterra, Para, Brazil were collected. All the studied individuals had botanic material collected and identified in herbarium by specialists of the Brazilian Agricultural Research Corporation – EMBRAPA.

Three trees of *Tachigali chrysophylla* were selected at random and branches residues after second bifurcation were collected. One radial board from each branch per tree was cut in samples of 20x20x40mm³ perfectly oriented, according to Moutinho et al. (2017).

The samples were carbonized in an electric resistance muffle furnace at three final temperatures (300, 400 and 500ºC) with heating rate of 1.6ºC.min^{-1} and residence time of 30 minutes. The charcoal apparent density were determined by mercury immersion method (VITAL, 1984) and the highest heating value in IKA C2000 adiabatic calorimeter bomb. The gravimetric yield on charcoal was determined based on dry mass of the wood and on mass of charcoal.

The mechanical strength and the modulus of elasticity at parallel compression of the fibers of charcoal samples were determined in a EMIC DL300KN universal tests machine, according to the methodology proposed by Moutinho et al (2017).

The study was carried out according to a completely randomized design, with three replications per individual for each used temperature (treatment), totalizing 9 (nine) samples per treatment.

The statistical analysis was performed using the software R Studio (R CORE TEAM, 2015), *agricolae* package, through normality and homogeneity tests and when positive for both a Tukey's test ($p<0.05$) was applied.

RESULTS AND DISCUSSION

The charcoal apparent density of *Tachigali chrysophylla* presented a higher value in final temperature of 300ºC, but differing statistically only in relation of 500ºC. For the highest heating value, there were significant differences among all the final temperatures, with higher value at 500ºC. The gravimetric yield on charcoal was significantly higher at 300ºC, with about 45%, followed by 400ºC e 500ºC with gravimetric yield close to 36.5% (Table 1).

Table 1 – Charcoalcharacteristics of *Tachigali chrysophylla* vary with the final temperature

Treatment	**AD (g.cm^{-3})**	**HHV (cal.g^{-1})**	**GYC (%)**	**MOE (MPa)**	**fc_0(MPa)**
300ºC	0.495 a	7173 c	44.81 a	318.64 b	9.45 b
400ºC	0.425 ab	7429 b	36.83 b	369.96 b	9.01 b
500ºC	0.391 b	7784 a	36.26 b	773.50 a	16.56 a

Where: AD = apparent density; GYC = gravimetric yield in charcoal; HHV= higher heating value; MOE = Modulus of elasticity; fc_0 = Strength to the parallel compression to fibers. Means followed by the same letter do not differ with $p<0.05$.

A decrease with the increase of final temperature of carbonization was observed. This can be justified due to the loss of material mass, between the interval of 300ºC and 500ºC, being higher than volumetric degradation, according to Trugilho and Silva (2001).

The charcoal of *Tachigali chrysophylla* residues presents apparent density proper to steel industry. Da Silva et al. (2007), when working with residues of three wood species in Para, obtained averages between 0.380 g.cm^{-3} and 0.530 g.cm^{-3} for carbonized charcoal in brickwork furnace, in large scale. Moutinho et al, (2017), when analyzing the properties of eight clones of *Eucalyptus*, which are the most used species in the national production of energy, observed values varying between 0.31 g.cm^{-3} and 0.39 g.cm^{-3}. It is important to highlight that the species in this study even not being genetically improved already demonstrates a high energetic potential.

Regarding higher heating value (Table 1), it is possible to observe that there was a significant difference among the applied treatments, as well as a directly proportional relation between the highest heating value and the final carbonization temperature. This result is according to Protásio et al. (2011) and Trugilho and Silva (2001) who state that higher temperatures result in higher fixed carbon content and, consequently, it results in a higher heating value of charcoal, due to the directly proportional relation between the two properties.

The results presented in this study for higher heating value are higher than results observed by Trugilho and Silva (2001). These authors observed values of 4833 cal.g^{-1} (300ºC), 5097 cal.g^{-1} (400ºC) e 5496 cal.g^{-1} (500ºC) for *Hymenaea courbaril L.* with the same heating rate of the study herein . Our results are also higher than Machado et al. (2014) e De Oliveira et al. (2006).

(Table 1) A decrease in gravimetric yield on charcoal with an increase in temperature were observed. An increase of final carbonization temperature causes a greater loss of mass, due to the decomposition of the wood chemical constituents. Machado et al. (2014) stated that this tendency occurs because of the longer time of exposure of the wood to the effects of thermal energy degradation.

The charcoal mechanical strength to the parallel compression of the fibers was significantly higher at 500ºC, with gains of 80% in relation to 300ºC and 400ºC, which did not differ among them (Table 1). In Figure 1, it is noted that this significant difference also occurred for the modulus of elasticity.

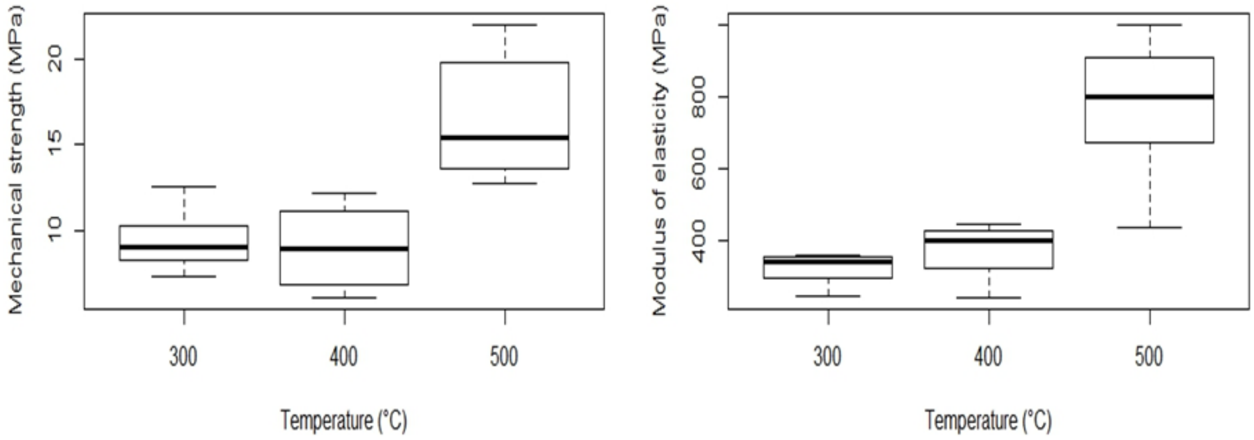

Figure 1 – Average values and standard deviation to mechanical strength observed at different final temperatures.

Moutinho et al. (2017) observed MOR between 7.32 and 13.62 MPa and MOE between 316 MPa and 535 MPa for *Eucalyptus* spp. at 400ºC and 1.6 ºC.min^{-1}, lower than the ones observed in the current study.

Vieira (2009) at final temperature of 550ºC observed maximum value of MOE of 699 MPa, lower than the current study for 500ºC. The MOE values present tendency to increase measure, thereby elevating the final temperature of carbonization, corroborating the information from Assis (2016) and Vieira (2009).

According to Blankenhorn et al. (1972), the higher mechanical strength of charcoal at 500ºC its due to the instability of graphite bundles formed between 300º e 500ºC and the cross-linking of fibril aggregates between 500 and 900ºC. Also, Couto et al. (2015) explain that the charcoal becomes more resistant due to the structural modification of its chemical constituents, reorganizing the crystallization of existing carbonic bonds with elevated thermal conditions.

CONCLUSION

The increase in final temperature of carbonization affects the charcoal properties. The lowest temperatures increase the apparent density and gravimetric yield of the wood charcoal.

The highest temperatures up to 500ºC increases the higher heating value and mechanical strength at compression parallel to fibers.

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