

Influence of the wood physical properties on the charcoal physical and mechanical properties

Influência de propriedades físicas da madeira sobre propriedades físicas e mecânicas do carvão vegetal

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Resumo

A qualidade do carvão vegetal depende significativamente das propriedades da madeira utilizada na sua produção. Atualmente, no Brasil, o maior produtor de carvão vegetal do mundo, este aspecto tem sido mais considerado visando, principalmente, o aumento da produtividade. Assim, a presente pesquisa objetivou analisar a correlação existente entre algumas características físicas da madeira com determinadas propriedades físico-mecânicas do carvão vegetal. Para tanto, foram avaliados oito clones de *Eucalyptus* e dois clones de *Corymbia*. Foram coletados discos dos troncos das árvores para a determinação da massa específica, umidade e contrações lineares e volumétricas. Posteriormente, as amostras foram carbonizadas em condições laboratoriais específicas, e o carvão produzido foi submetido a análise de densidade aparente, resistência à compressão paralela às fibras e degradação linear e volumétrica devido aos efeitos da temperatura. Em seguida, para uma melhor interpretação dos resultados, analisou-se conjuntamente as propriedades da madeira e do carvão vegetal por meio da técnica estatística multivariada de correlação canônica. Concluiu-se que a massa específica e a umidade da madeira são os fatores de maior correlação significativa com as propriedades estudadas do carvão vegetal.

Palavras-chave: física da madeira, propriedades mecânicas do carvão vegetal, eucalipto, correlação canônica.

Abstract

The quality of charcoal is strongly dependent upon the characteristics of the wood from which it originated. In Brazil, the world's largest charcoal producer, this aspect has received special attention to increase the industrial productivity. The present study aimed to analyze the correlation that exists between some physical characteristics of wood and some physical and mechanical properties of the charcoal. Eight clones of *Eucalyptus* and two clones of *Corymbia* were studied. Discs from the trunk of the trees were collected to determine the specific gravity, humidity and linear and volumetric shrinkage of wood. After that, the samples were carbonized under specified laboratory conditions and the generated charcoal was analyzed regarding its apparent density, resistance in compression parallel to the grain and linear and volumetric degradation due to the action of temperature. To evaluate jointly the charcoal and wood properties, the multivariate technique of canonical correlation was used. It was concluded that specific mass and wood humidity are the most important correlation factors with the charcoal properties under study.

Keywords: physical properties of the wood, charcoal's mechanical properties, eucalyptus, canonical correlation.

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INTRODUCTION

According to EPE (2013), nearly 26% of the Brazilian energy consumption originates from biomass. The wood and its energetic derived products represent 33% from this total. Around 32% of the wood used for energy, or about 25 million tons, is transformed into charcoal.

Presently Brazil can be considered the biggest producer and consumer of charcoal in the world. This is due to the fact that the country (i) has great mines of iron oxides, and (ii) does not possess coal mines with enough quality for the reduction process of that mineral. Since the edaphic and climatic factors favor high forest productivity, the iron industries instead use charcoal on a large scale.

The energy demand led to the planting of approximated 6,5 million hectares, or about 0,75% of the country's territory, producing 162,6 millions cubic meters of wood and generating, on average, 4 million of direct and indirect jobs (ABRAF, 2010; SBS, 2008). From this total, in 2009 *Eucalyptus* represented 66% of the planted forest area, from which 20% are used for charcoal production (ABRAF, 2010).

Charcoal quality is highly dependent on the wood characteristics from which it originated. It is hoped that the charcoal used in the reduction process has a high fixed carbon content; a low amount of volatile materials and minerals; as well as high mechanical strength (VALE et al., 2011; ROCHA; KLITZKE, 1998; BRITO, 1993; GOMES, 1982; GOMES; OLIVEIRA, 1980;).

Along with the need of eucalyptus genetic improvement to steer the improvement programs, with management and forest nutrition for charcoal production; it is necessary to understand the influence of the physical properties of the wood on the physical and mechanical properties of charcoal. After determining the influence of these properties, it is possible to create a parameter to better identify its interference on mechanical resistance, apparent density and gravimetric yield, which are essential to determine the utilization and improvement of charcoal. This work analyses these properties in different eucalypt clones. A multivariate analysis technique of canonical correlation was applied to evaluate which physical wood proprieties influence various characteristics of charcoal.

MATERIAL AND METHODS

Eight different clones of *Eucalyptus* and two of *Corymbia*, aged six years, in the State of Minas Gerais – Brazil, were used. The silvicultural treatments were identical for all the analyzed clones.

For each clone studied, three trees were culled, giving a total of 30 trees. After cutting, 15 cm thick discs of wood were taken at six different heights (0, DBH, 25, 50, 75 and 100% of the trunk). The smallest diameter limit was 6 cm with bark.

From the discs 2 x 2 x 4 cm samples were made, corresponding to the tangential, radial and axial direction respectively. The number of samples taken from the disc depended on the diameter of the wood along the height of tree trunks, with approximately 25 samples per tree; or 75 samples per clone.

The wood samples were identified and saturated in water to determine its physical properties. Then the samples were kept in an oven with forced air circulation (100° C) until reaching 0% humidity, in order to determine its (i) humidity; (ii) specific gravity and (iii) total linear and volumetric shrinkage. The volume of wood samples was obtained by the mercury immersion method.

The wood samples were transferred to a muffle furnace with an electric resistance. The carbonization process was done at a rate of 1° C/min to 400° C, which was kept for 60 min. The muffle furnace was kept closed until the return to the ambient temperature, when the samples were removed and analyzed. Determined were: (i) gravimetric yield on dry charcoal base; (ii) linear/volumetric degradation of the samples of charcoal for later comparison with the samples of dry wood.

The linear dimensions of charcoal samples were determined in the same position used on the wood samples, obtaining the percentage values inherent to the thermic degradation after carbonization; the samples' volume was obtained by the mercury displacement method, and the mass on a precision scale – as described – obtaining the charcoal density values.

For the mechanical tests of strength in compression parallel to the charcoal fibers, an universal machine was used, model EMIC DL-30000. Due to the absence of a specific standard that could direct the work of mechanical tests in charcoal, extra samples were carbonized in order to understand the charcoal behavior and obtain preliminary results in order to obtain an idea which could explain the results in a consistent way.

A rate of motion of crosshead of 0.2 mm/min was used and a collapse detector was inserted for the abrupt loss of 20% of the material resistance, indicating the rupture of the sample and the destruction of its structural arrangement, which ended the test. Strength to compression and the modules of elasticity were obtained; the latter was calculated by means of a secant line from the graphic of the force exerted by the material deformation at the points between 60 and 120 Kgf.

It has to be emphasized that, after obtaining data of the properties of wood and charcoal, those were weighted considering the position in the disc area and height of it, aiming to provide a greater accuracy of the mean values.

In order to verify the correlation of wood and charcoal properties and the existent association between these two clusters a multivariate analysis of canonic relation with test lambda from Wilks of 1% significance was applied. In the Canonic correlation test the wood variables as independents (X') and of charcoal as dependents (Y') were used, thus obtaining two different clusters: X' and Y' ; where:

X' [x_1, x_2, \dots, x_p] is the vector of measures of p characteristics that constitute the group I (wood), and Y' [y_1, y_2, \dots, y_q] is the vector of measures of q characteristics that constitute the group II (charcoal). Thereby we have the basic expression of canonic correlation given by:

$$X_1 + X_2 + X_3 + \dots + X_p = Y_1 + Y_2 + Y_3 + \dots + Y_q.$$

Wherein:

$$X_i = a_1 x_{i1} + \dots + a_{ip} x_{ip}$$

$$Y_i = b_1 y_{i1} + \dots + b_{iq} y_{iq}$$

We defined values $a' = [a_1 \dots a_p]$ and $b' = [b_1 \dots b_q]$ as vectors of weights of characteristics corresponding to the clusters 1 and 2, respectively. Therefore was possible to estimate the canonic charges, in other words, the correlations between the original variables and its respective canonical statistical variables and the canonical charges crossed that represent the correlation between an original variable of a determined group and the canonical statistical variable of the other group.

Since the canonic correlation has the aim to develop a linear combination in each one of the sets of variables (X' and Y') in order that the association be maximized, we obtained the first canonic correlation of canonical pairs X_1 e Y_1 . For the significance test of each canonic correlation a chi-square distribution (X^2) was used with $p \times q$ degrees of freedom.

RESULTS AND DISCUSSION

From the six canonical pairs obtained, only one pair was significant by the test of Wilks (Table 1).

For Trugilho et al. (2003), the analysis of canonic correlation provides a simple way to reduce the complexities involved in relating two clusters of variables, where the main problem resides in the technique that refers to the interpretation of canonic solutions, due to the high heterogeneity of the variables.

From the obtained results it can be inferred that the specific gravity of the wood has a significant positive relations with apparent density of the charcoal, being related also to the modules of elasticity, RPCF, gravimetric yield, linear radial, axial and tangential degradation.

The wood's specific gravity results from a summation of parameters which involve, for example, the cell wall ultra-structure, chemical composition and variation of the anatomic elements of the wood, generating a complex result; but this is very useful to evaluate the products coming from the wood.

Considering that the carbonization process depends directly on the anatomic structure, which interferes in the mechanic resistance of the charcoal due to the drying process; and the chemical composition also contributes directly in the generation of charcoal, among other factors; then the significant influence of density on the different properties of charcoal is understandable.

The positive and significant relation between specific gravity of the wood and the apparent density of charcoal have already been related by Trugilho et al. (2003), Brito and Barrichelo (1980), Byrne and Nagle (1997), Vale et al. (2010), Vale and Nogueira (2001), Zanuncio et al. (2014). This explains the fact that, the bigger the wood's specific gravity, the bigger is the mass of this material in

different fundamental components; as lignin, which helps in the generation of a larger amount of carboniferous residue in an equal volume, when compared to a lower density wood.

The gravimetric yield is positively correlated with the wood's specific gravity, which contradicts the results found by Trugilho et al. (2003), Brito and Barrichelo (1980), Vale et al. (2010), Vale and Nogueira (2001), Santos et al. (2011). However, all the cited works had methodological differences that explain the variance results. While Vale and team used material coming from the Brazilian savanna and with little diameter, about 16 cm to 30 cm from the soil, Brito and Barrichelo (1980) limited themselves to discs at DBH. Trugilho et al. (2003), on the other hand, despite the great quantity of samples at different heights, did not present the weighing of the values in their work, as did other authors. Therefore, the factor weighing added in this work may have aided a new statistical interpretation of the obtained data. We emphasize that this result supports the one found by Pereira et al. (2010).

Table 1. Canonic correlation between physical properties of the wood and the produced charcoal and test of Wilks at 1% of significance of the canonical pairs obtained.

Tabela 1. Correlação canônica entre as propriedades físicas da madeira e o carvão vegetal produzido com teste Wilks a 1% de significância para os pares canônicos obtidos.

Matrix	Variables	Canonical pairs					
		1	2	3	4	5	6
Wood	Tangential Contraction	0.130	0.598	-0.027	0.671	-0.415	0.043
	Radial Contraction	-0.399	-0.158	-0.484	0.605	0.411	-0.216
	Volumetric Contraction	-0.191	0.444	-0.282	0.823	0.065	-0.076
	Specific Gravity	0.956	0.106	-0.268	0.000	0.007	-0.044
	Total Humidity	-0.811	0.391	-0.131	-0.290	-0.289	-0.070
	Anisotropy Coefficient	0.438	0.468	0.375	-0.130	-0.600	0.266
Charcoal	RPCF*	0.612	-0.524	-0.055	-0.156	-0.014	-0.028
	Modules of Elasticity	0.823	-0.150	-0.057	-0.115	0.108	0.032
	Tangential linear degradation	0.600	-0.362	0.140	-0.062	-0.122	-0.056
	Radial linear degradation	0.758	-0.148	0.079	0.205	0.017	0.032
	Axial linear degradation	-0.082	0.251	-0.187	0.342	0.058	0.037
	Volume Degradation	0.217	0.016	0.094	-0.172	0.232	-0.015
	Gravimetric Yield	0.725	-0.136	-0.076	0.111	-0.056	0.024
	Apparent Density	0.902	-0.101	-0.085	-0.082	-0.062	-0.030
Wilks	Canonic Correlation	0.96	0.78	0.69	0.48	0.43	0.24
	Value of p	0.000	0.129	0.403	0.737	0.681	0.740
	Significance	*	ns	ns	ns	ns	ns

*Resistance to compression parallel to the charcoal fibers

The RPCF and the elasticity module present positive relations with wood specific gravity; however, no literature was found referring to the comparison effect. It is known that the higher the wood density, as a rule, the higher is the resistance of the material, resulting in a similar behavior in the charcoal. Slocum et al. (1978), verified the inclination that, the higher the wood density, the larger is be the mechanical resistance of the charcoal; however the authors did not perform a statistical analysis to verify the significance of this inclination.

Issues such as wood linear and volumetric contractions have contributed little to the properties of charcoal, and the anisotropy coefficient was not very significant. Perhaps this may be explained by the carbonization process itself, because independently of the way that the cellulose micro fibrils rearrange within the wood, they will be degraded in different other components due to the action of the temperature. The contractions and the anisotropy coefficient are important during the drying process of the wood, mostly by the formation of cracks, which are harmful to the mechanical resistance of the material.

Wood humidity, on the other hand, due to the high negative correlation with the charcoal's density, resulted in a negative relation with desirable characteristics for charcoal.

Higher humidity in the wood results in more fragile charcoal due to steam escape from the tissue. This in turn helps in crack formation, thereby affecting the mechanical properties of the charcoal.

On other hand, water interferes in the carbonization process; as the heating rate gets very high, which leads to a more heterogeneous carbonization. However, the heterogeneous contraction could also adversely affect the internal structure / mechanical properties of the resulting charcoal.

CONCLUSION

According to the canonical correlation analysis, individuals with greater specific mass correspond to a charcoal of greater mechanical resistance, gravimetric yield and apparent density, while individuals with higher humidity values produce charcoal with lower mechanical resistance.

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