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MOIRÉ OPTICAL TECHNIQUE FOR EVALUATION OF CASHEW NUTS (*ANACARDIUM OCCIDENTALE, L.*) ISOSTRAIN

ABSTRACT: A figure corresponding to 96% of Brazilian cashew nuts production is forward to industrial processing whose yield is only 50 to 60% of the whole kernels. An appropriated knowledge of nut mechanical behavior would be important to support the development of an equipment designed to minimize losses during processing. The nut shell is composed by three layers identified as epicarp, mesocarp and endocarp, which exhibit distinct behaviors and mechanical solicitations. An important class of mechanical loading is recognized to be the contact stress which is generated from the pressure exerted between two elastic bodies in contact. However, the structural as well as the geometrical complexity of the nut ask for a suitable methodology to investigate stress distribution in cashew nuts. Shadow *moiré* technique was identified to support a suitable stress analysis method for the present case. Ten nuts were submitted to the trials, being 5 scarified nuts shells and 5 non scarified. A conventional optical setup was prepared to support a shadow *moiré* test. The pixels of images were defined as light intensity of loaded image that generates a pixel of relative strain values. It was observed a close correlation between external and internal load distribution. Isodeformation distribution, suggested by the figures, is not in agreement to Hertz Contact Stress Theory, due to the material anisotropy. The technique was efficient and obtained a qualitative correlation of deformation distribution in the endocarp, as well as in the epicarp.

KEYWORDS: Shadow moiré; mechanical behavior; biological material.

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TÉCNICA DE MOIRÉ PARA AVALIAÇÃO DA ISODEFORMAÇÃO DE CASTANHAS DE CAJÚ (*Anacardium Occidentale, L.*)

RESUMO: No panorama atual 96 % da produção brasileira de castanha de caju é encaminhada para processamento industrial com rendimento de apenas 50 a 60% de amêndoas inteiras. O conhecimento apropriado do comportamento mecânico das castanhas é importante para desenvolver equipamentos com o objetivo de minimizar as perdas durante o processamento. A casca da castanha é composta por três camadas, identificadas como epicarpo, mesocarpo e endocarpo, que exibem distintos comportamentos mecânicos a solicitações. Uma importante classe de carregamentos mecânicos se refere a tensões de contato que exercem tensões entre dois corpos elásticos em contato. No entanto, a estrutura, assim como a complexidade da geometria da castanha dificultam uma metodologia para investigar a distribuição de tensões nas castanhas de caju. A técnica de Shadow moiré tem potencial para analisar a distribuição de tensão no presente caso. Foram submetidos a triagens castanhas de caju, sendo selecionadas dez espécimes, cinco tendo o epicarpo retirado e cinco não. Um arranjo experimental convencional para obtenção das franjas de moiré foi preparado. Os pixels das imagens foram definidos como intensidade luminosa da imagem carregada, que gera um pixel de valor relativo a deformação Foi observada um forte correlação entre as distribuições de tensões externas e internas. A distribuição de isodeformações sugerida pelas figuras não concorda com a teoria de tensão de contato de Hertz devido a anisotropia do material. A técnica se mostrou eficiente para a obtenção de uma correlação qualitativa da distribuição de deformações no endocarpo, assim como no epicarpo.

PALAVRAS-CHAVE: Moiré de sombra; comportamento mecânico; material biológico.

INTRODUCTION

Cashew nuts industrial processing includes several steps as shelling to liberate the endocarp, which exhibits low yielding and bruises as high as 40 to 50% to the shelled nuts. Cashew nuts industry is looking for an improvement on yield and minimizing bruising occurrence by acquiring knowledge of a mechanical behavior of a product to support equipment project and development. Cruz (2007) states that it is important to preserve and keep its maximum quality during post-harvest when considering applied forces for cracking.

However, the *moiré* optical technique, to be used in this investigation, seems to be an adequate tool, which is able to provide some qualitative discrimination for engineering purposes. Cashew nut shell is divided into three layers named as epicarp, the external cover; mesocarp, the intermediate layer containing the shell liquid and the internal one that is the most resistant layer, named as endocarp (ARAÚJO et al., 2004). Guner; Dursun and Dursun (2003) have pointed out that the most critical and delicate operation on nut shell is during its cracking since it is necessary to extract the whole fragile kernel from the shell. These layers show different responses to diverse mechanical loading, including an important situation known as contact stress, generated by the pressure exerted between elastic bodies through infinitesimal contact areas. The solution of such problem is supported by classical mathematical models, which consider the bodies to exhibit ideal elastic behavior, and curved surface pressed one against another by means of external excitations.

Frequency and level of contact pressure will limit the product life (ANTONIALI et al., 2007), which is associated to endocarp as well to the shell tissue mechanical failure. The most important stresses are observed to be higher at the shell surface when compared to the inner part of the nut. This stimulates the problem of determining the maximum compressing from the main shear stresses at nut shell surface.

Hertz theory requires that the contact stress between convex bodies and flat surfaces should not involve slippage. The material should be homogeneous, isotropic and elastic and it should keep contact through a single point. These conditions limit the application of Hertz theory to biological material (MOHSENIN, 1986).

The objective of shelling is to let the whole endocarp free of bruising. The most adequate load application directions can constitute important parameters to conceive shelling mechanisms. However, due to the geometrical and structural nuts shells complexities, which difficult the approximation of an analytical expression for stress and strain relationship, the relations developed in the endocarp were investigated, due to the application of loads on epicarp. Based on the above information, the objectives of this research can be stated as to compare the deformation distribution on cashew nut epicarp as well as on the corresponding deformation on endocarp by means of a shadow *moiré* technique. Optical interferometric technique consists in generating and interpreting interference fringe patterns.

By looking through superposed screens, a set of fringe patterns is observed, as a result of the screen lines combination which is called *moiré* phenomenon or *moiré* effect. Cloud (1998) mentioned that *moiré* fringes are suitable to magnify displacement which could provide high sensitivity to relative displacement measurement. Shadow *moiré* technique is used to measure out of plane displacement (POST; HAN;

IFJU, 1994). Hu (2001) stated that shadow as well as projection *moiré* techniques are very popular perfilometric methods due to their simplicity and quick measuring, thus, they are considered suitable for several different application areas, so they are frequently a subject of research.

Light is propagated in a wave form and is mathematically described according to the wave function (SALEH; TEICH, 1991). When two or more coherent light waves of the same frequency and amplitude are simultaneously in the same space region, the total wave function is the sum of these waves and due to interference, its resulting intensity depends on the relation of phases among superposed waves (SALEH; TEICH, 1991). Such interference can generate a standard of clear and dark fringes.

Moiré patterns can be understood as the superposition of two waves which keep a certain angle between their propagation directions. Regions in which these two waves are in phase, fringes are clear due to constructive interference and in regions where waves are out of phase, fringes are dark (MALACARA, 1992). That derivation comes from the interference between fringe patterns by means of relationship named initial transition models (PISAREV; BALALOV, 2001).

This study aims at comparing the distribution of deformations in the epicarp (surface) and the corresponding internal deformations (endocarp) using cashew nuts ‘CCP 76’, based on the *moiré* optical technique.

MATERIAL AND METHODS

The studied cashew nuts were obtained from EMBRAPA (National Center for Tropical Agroindustrial Research in Fortaleza, Ceará, Brazil). A set of 25 *in nature* nuts was immersed into water for two hours and followed by a 86 hour resting period in a closed pot. The material was then fried in cashew nut shell liquid (CNSL) at 210 ^{0}C during 150 seconds, followed by a resting period of 02 hours.

Ten cashew nuts were separated and five of them were scarified by a sharp knife to remove the epicarp and mesocarp, but the kernel involved by endocarp was left. Each one of them was weighed on an analytical scale with 0.1 g of precision and characterized according to their main dimensions by a DIGIMESS digital caliper with 0.01 mm of resolution, as it is shown on Figure1. Kernel involved by endocarp and the whole nuts surface were covered with white opaque stain. Fifteen cashew nuts were preserved to be used if there was any problem. *In nature* moisture content was determined by means of the ASAE S410.1 (ASAE, 1997), 1994 norm.

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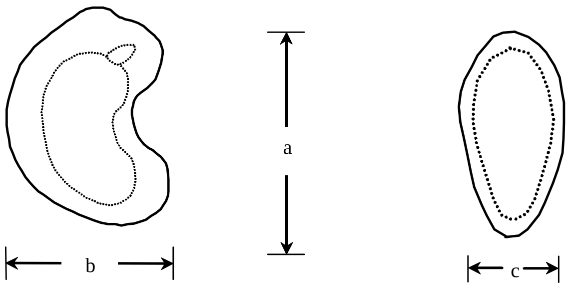

Figure 1 Characteristic dimensions of cashew nuts and kernel plus endocarp. Length (a), width (b) and thickness (c).

Experimental setup is shown on Figure 2. It was composed by a 500 W Sawyers Grand Prix 730 RI slide projector, with white light source; a Sony P32 digital camera with 3.2 Mpixels and by a grid with 0.4 mm period and bar thickness of 0.4 mm. The camera was fixed on an adjustable tripod at the same height as the light source, which was placed on a table, meanwhile the grid was placed at 5mm from the specimens. The setup geometry was designed to optimize fringes contrast keeping an angle of 25^0 between the camera, the light source and the specimen, as shown on Figure 2, maintaining a 380 mm distance between the light source lenses and the camera iris.

The distance between the plane generated by light source plane and camera iris to the grid plane was kept as 710 mm. These conditions are very close to those ones mentioned by Post (1994), in which fringes exhibit excellent visibility when bars width and space between bars is equal, bar contours are well defined, angle between light source axis and observer line is small and finally when the ratio of the spaces between bars is less than 1.05:1.

The applied shadow *moiré* method consists in superposing a grid on its own shade in order to generate fringes similar to contour lines. This means that they are formed by points of same height, similar to topographic maps. A strain of 0.05 mm/mm was applied to the specimens as indicated on Figure 3, by means of an OTTOWA TEXTURE MEASURING SYSTEM testing press. Specimens were positioned between parallel rigid plates to reach the whole specimen surface. A digital picture was taken for each specimen, before and after test and just after the established strain had been reached to avoid viscoelastic effects.

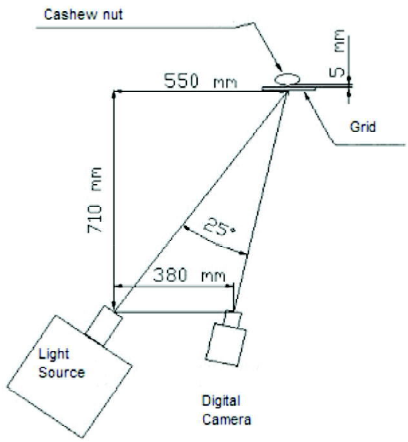

Figure 2 Experimental setup to generate moiré fringes on the specimen surface.

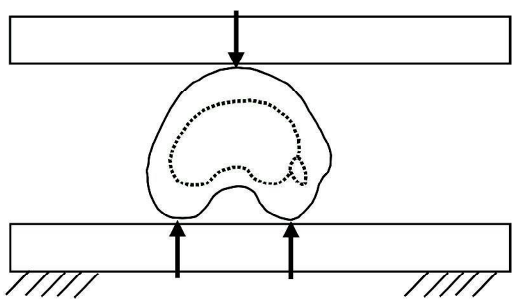

Figure 3 Specimen compression between two parallel rigid plates at a strain level of 0.05mm/mm, emphasizing contact points.

METHODOLOGY OF ANALYSIS

JPEG photos were converted to BMP in gray levels by means of the GIMP version 1.1.24 (KIMBAL; MATTIS, 2001) where the gray shade. Zero was defined as the dark color and 255 was defined as the white one. In order to interpret the results, each gray shade was a specific color. As recommended by Post, (1944), the method known as the whole field subtraction was applied by subtracting pixel by pixel of a loaded specimen photo X_i , from the loaded specimen photo X_{i+1}. This method allowed determining the undergone deformation generated by two different loading levels.

The analysis was carried out through the Labs IDRISI software, version 32, that is a powerful imaging processor. The methodology was applied to do a treatment of images in JPEG format and to eliminate noise occurrence. After this step, the photos were standardized for the use of low-pass and Gaussian filters with interpolation matrices of 3 and 4 dimensions respectively, and the gray scale was defined. As the gray scale was defined, it was possible to analyze deformation. The statistical analysis of kernel plus endocarp dimensions and mass were obtained through the descriptive statistic using arithmetic average, standard deviations and the coefficient of variation.

RESULTS AND DISCUSSION

The average water content of cashew nut was 9.05% dry basis. On Table 01, it can be seen the whole nut as well as kernel plus endocarp dimensions, from which it can be observed 4% of variation for length, width, thickness and 13% for mass of cashew nut.

Table 1 Average dimensions and mass of nut and kernel plus endocarp.

	Cashew Nuts			
	Length	Width	Thickness	Mass
01	36.75	30.58	21.59	6.6
02	34.89	27.89	20.34	5.8
03	36.22	29.53	22.49	6.8
04	37.32	29.78	21.87	7.8
05	33.64	27.67	20.65	5.7
Average	**35.76**	**29.09**	**21.39**	**6.54**
SD*	**1.49**	**1.26**	**0.88**	**0.85**
CV**	**0.04**	**0.04**	**0.04**	**0.13**
	Kernel plus endocarp			
	Length	Width	Thickness	Mass
01	29.71	23.92	15.7	3.6
02	29.58	22.24	14.82	3
03	30.58	23.1	14.73	3.1
04	28.91	20.11	14.33	3
05	30.69	21.1	14.65	3.3
Average	**29.89**	**22.09**	**14.85**	**3.20**
SD*	**0.74**	**1.52**	**0.51**	**0.25**
CV**	**0.02**	**0.07**	**0.03**	**0.08**

* Standard Deviation   ** Coefficient of variation

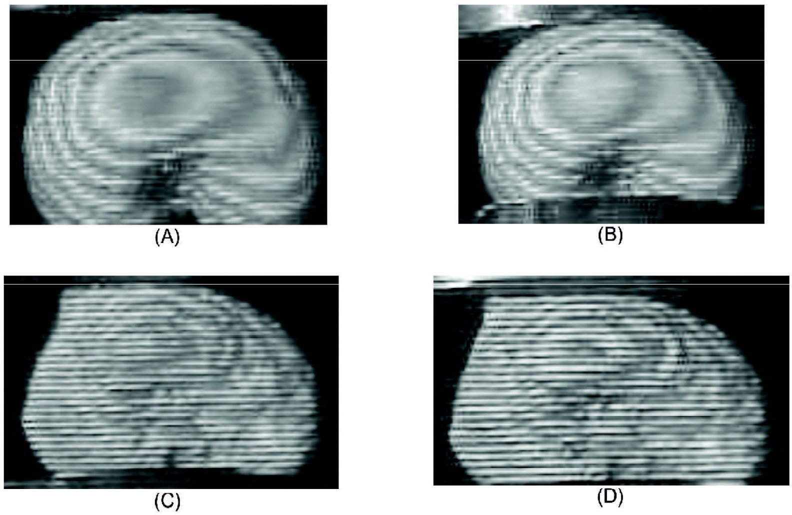

Figure 4 The whole cashew nut specimen (A, B) and kernel plus endocarp (C, D), respectively with 0.05 mm/mm strain and without deformation.

After processing the five photos of cashew nuts, it was observed that all of them showed similar isodeformation tendency, enabling to select the whole cashew nut (Figures 4 A and B) as well as kernel plus endocarp (Figures 4 C and D) photos exhibited the best resolution. From these figures, it can be seen that the bottom of photo was cut off to optimize fringe contrast due to the equipment repositioning. On Figure 4, fringes are shown before loading (A and C) to emphasize pattern changes after loading at a strain rate of 5% (B and D). Results from image processing are observed on Figures 5 and 6.

Isodeformation maps showed regions of same deformation that were identified as pixel groups of same grade, referring to the figure plane deformations, i.e. orthogonal to the plane defined by the image. Each image pixel is defined as a light intensity referenced in gray level, from 0 to 255 level in such a way that the subtraction of a pixel from undeformed specimen image by a deformed specimen image pixel will generate a qualitative pixel, which informs the deformation level experienced by the specimen region under consideration.

These scales have exhibited a qualitative character rather than a quantitative one, showing the signals (+) and (-) to emphasize larger and smaller deformations, respectively. On Figure 5, there are seven different deformation levels, in which the green color indicates the largest deformation level and the dark color indicates the lowest one. However, on Figure 6, five deformation levels were identified, in which the dark color indicates the largest deformation level and the red color indicates the lowest one. The registered deformations in this figure refer to displacements at **z** direction, as indicated on Figures 5 and 6.

It can be noticed on Figure 5 that regions of larger deformations at **z** direction are found at the specimen center as well as on the bottom and in the left border, meanwhile the region of the smallest deformation is at upper right border. As the load is applied for cashew nut width, the largest deformation at **z** direction is expected to occur at the specimen center, which is confirmed by this Figure.

Similar behavior is observed on kernel plus endocarp, as it is presented on Figure 6. Lino, (2002) reports the occurrence of fringe sharpness to solve problems on highly curved surfaces which might induce to interpretation errors. In this trial, the subtraction between the values given to the pixels analyzed the relative differences between pixels which neutralize possible border errors. Lino (2002) reported that, in spherical objects, there are problems of sharpness and resolution of fringes at the object edges with high curvature that might cause errors on data interpretation. In this trial, the applied technique is based on the subtraction among pixels, so it is analyzed the relative difference of each pixel, which neutralizes possible errors on the edges of cashew nut and almond.

It should be emphasized that such analysis is qualitative that has to be developed before aiming further quantitative procedures. The color scales displayed together with processed images in shadow *moiré* technique have defined the iso-strain maps under compressive loading, referring to pixel to pixel subtraction that generates the image matrix. It was possible to visualize fringes displacement during specimen compression, however, out of plane deformations, as shown on Figures 5 and 6, could not be observed during the tests.

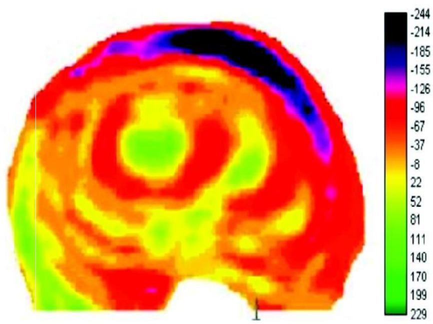

Figure 5 Isodeformation maps for strain rate of 0.05 mm / mm on cashew nuts.

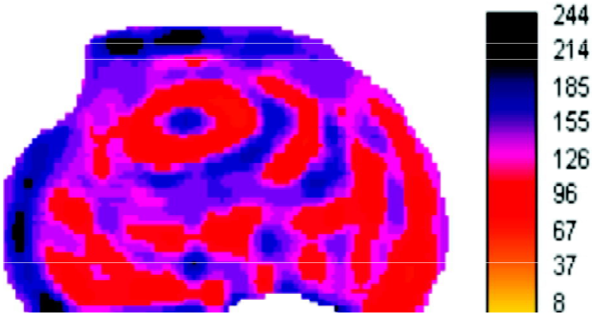

Figure 6 Isodeformation maps for strain rate of 0.05 mm/mm on kernel plus endocarp.

From isodeformation maps, it is possible to show the deformation distribution on the whole nuts as well as on kernel plus endocarp. It can be observed from Figures 5 and 6 that there is a close correlation between deformation distributions on epicarp and on endocarp that allows a prediction of deformation occurrence on kernel plus endocarp by means of an external analysis of the loads and deformation on cashew nut. Isodeformation distribution, suggested by the figures, is not in agreement to Hertz Contact Stress Theory due to the anisotropic material. And with the small camera resolution, it was necessary to adapt the experimental setup to improve fringe contrast. This generated an undesired fringe deformation, which is related to the distance between the grid and the object. In this case, the projection of light beam that follows an angular geometry induced an error", which is translated as a bad fringe formation, generated by the grid shade magnification.

The defective fringes generated 'isle' of isodeformation. Post (1994) stated that to avoid such occurrence, it is necessary to set the distance between camera and a light source the same as the reference object plane. The application of collimated and coherent light source together with appropriate and optimized setup geometry would generate better fringe definition. In future setup, these improvements will be implemented.

CONCLUSION

The pixels of images were defined as light intensity of loaded image and it generates a pixel of relative strain values. The shadow *moiré* technique was able to conclude that there is a correlation between isodeformation of cashew nut shell and kernel. Isodeformation distribution suggested not agreeing with Hertz contact stress theory due to material anisotropy.

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