

Some Experimental Results of Papyrus Physical Properties

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Abstract. Papyrus plays a profound role in ancient Egyptian civilization. The invention of writing system required a flexible and movable material that may last as long as the included message existed. This research provides the results of experiments that carried out on modern Egyptian papyrus. The physical properties; density, color, shrinkage scale and brightness of recently harvested papyrus stems are studied. The factors that monitor these properties; such as, age, area of the strips, harvesting time, ...etc are also investigated.

Papyrus mechanical properties; tensile for example introduced this material as a cultural permanent media valid for all purposes; writing, painting and stuffing (cartonage). This paper includes experimental data that answers the reasons why ancient papyrus are still remained preserved in good conditions up to the moment.

Papyrus of April for instance gives the best appearance towards the color, brightness as well as mechanical properties when compared to January, February and March papyrus. These results were enhanced by the analytical FTIR data of the functional groups of lignin products.

Introduction

Making paper from the papyrus plant is one of the most remarkable inventions in ancient Egypt. Papyrus, also paper reed, is a common name for a plant of the sedge family¹. The plant

¹ Sedge, common name for a family of grass like flowering plants with characteristically triangular stems. The family is worldwide in distribution but is particularly abundant in wet, marshy areas of the temperate and subarctic zones, where it is ecologically important in binding and stabilizing soils. The family contains about 115 genera and 3600 species.

Members of the sedge family typically possess a rhizome, a root like underground stem out of which grows a tuft of basal leaves. The leaf bases expand into sheaths that entirely close around the stem. The stem itself is usually unbranched and leafless, with a cluster of inconspicuous flowers at its tip. Each flower is borne in a single bract (modified leaf) and has either no perianth (floral envelope) or one reduced to a series of scales or bristles rather than showy petals. Sedges are generally distinguished from grasses by their triangular stems and by leaves with closed sheaths.

The family is of some economic importance. Stems and leaves of many genera, including the bulrush, are used for

grows about 1 to 3 m high, some species grows up to about 5 m, and has a woody, aromatic, creeping rhizome. Papyrus is by far the tallest of the botanical genus *Cyperus*. The leaves are long and sharp-keeled, and the upright flowering stems are naked, soft, and triangular in shape. The lower part of the stem is as thick as a human arm, and at the top is a compound umbel of numerous drooping spikelets, with a whorl of eight leaves. Papyrus grows in Egypt, in Ethiopia, in the Jordan River valley, and in Sicily (Duke, James. A. 1983).

Cyperus papyrus consumes a great quantity of water and therefore grows in still water and swamps successfully. Roots stretched horizontally under the mud and from this rises several stalks, triangular in section. The stalk of

weaving mats, baskets, and hats, as well as in papermaking. The paper reed was the source of ancient Egyptian papyrus. One genus in the sedge family includes species used for hay and packing materials. Cotton grass is used in pillow stuffing.

the papyrus plant has a tough green rind which conceals a white pith composed of a mass of cells with occasional vascular bundles, the vegetable equivalent of arteries, which carry water and sustenance from the root to the flowering head.

It is difficult to identify botanically the ancient writing materials from the surviving examples because it is made from the core of the plant stem, which may not vary greatly from one sub-species to another. Without the precise plant type, details such as the rate of production remain unknown. The chemical composition of the papyrus plant varies between sub-species or between specimens grown in different places and this can affect the its suitability for specific use.

Various parts of the papyrus were used in antiquity for both ornamental and useful purposes, including wreaths for the head, sandals, boxes, boats, and rope. The roots were dried and used for fuel. The pith of the stem was boiled and eaten, but it was used mainly in making papyrus, the sort of paper that was the primary writing material of classical antiquity. Papyrus was also useful for medicinal purposes².

The papyrus of the Egyptians was made of slices of the cellular pith laid lengthwise, with other layers laid crosswise on it. The whole was then moistened with water, pressed and dried, and rubbed smooth with ivory or a smooth shell. Several techniques for papyrus processing to make sheets has been mentioned in the literature (Wallert, 1988). The sheets of papyrus, varying from about 12.5 by 22.5 cm to about 22.5 by 37.5 cm, were made into rolls, probably some 6 to 9 m in length. The Egyptians wrote on papyrus in regular columns, which in literary prose rarely exceeded 7.6 cm in width; in poetry the columns were often wider in order to accommodate the length of the verse.

The Greeks seem to have known papyrus as early as the beginning of the 5th century BC, but

the earliest extant Greek papyrus is believed to be the *Persae* of the poet *Timotheus*, who lived during the 5th and early 4th century BC. The use of papyrus for literary works continued among the Greeks and the Romans to the 4th century AD, when it was superseded by parchment. It was still used for official and private documents until the 8th or 9th century.

Scientific classification: Papyrus belongs to the family *Cyperaceae*. It is classified as *Cyperus papyrus*. Scientific classification: Sedges make up the family *Cyperaceae*. Bulrushes belong to the genus *Scirpus*. The paper reed is classified as *Cyperus papyrus*. The sedge species used for hay and packing materials are classified in the genus *Carex*, and cotton grass in the genus *Eriophorum*.

Materials and Experiments

This paper discusses results of some experiments that are carried out in Egypt. Papyrus sheets were manufactures from *Cyprus papyrus* that are harvested monthly over a year to study the parameters that control the best quality of papyrus sheets that are used either for writing or for painting purposes. In addition, to study the manufacturing techniques and the better process sequence, different methods and scheme were followed.

Wiedemann (Wiedemann, 1979) mentioned that both of the age and area in the papyrus plant influence the papyrus properties. Several studies have been carried out in the broad range of investigation for remanufacturing of papyrus following the ancient techniques (Ragab, 1980) The thermal analysis (DTA) of papyrus samples confirmed that Egyptian papyrus samples have less lignin-content than Cyprus ones. It is found also that the older the plant the lesser the lignin-content.

Methods (Sturman, 1987)

In order to study the different properties of papyrus, fresh papyrus sheets were prepared as follows;

1. Five bunches of papyrus reeds, 20 to 25 stalks each, are harvested over a year long.
2. The outer green rind is removed using a sharp cutter.
3. The inside white pith are sliced by a mechanical cutter into manageable longitudinal thin and even strips in order to get the thickness of the strips homogenous.

² Galen, Dioscorides and later Islamic pharmacologists, e.g. Ibn-Gulgul and El Ghafiqi, included papyrus among medicinal plants. The pith was recommended for widening and drying of fistula. The main use, anyhow, seems to have been confined to burnt papyrus sheets, the ash of which was reputed to have the action of pulverized charcoal and used for certain eye diseases. Dioscorides (in 78 AD) writes that its ash checks malignant ulcers from spreading in the mouth or elsewhere. Galen (129-200 AD) says that the plant is not used in a raw state but if macerated in vinegar and burnt, the ash heals wounds. Europeans also list this among their folk cancer cures. Duke, J.1983. *op cit*.

4. Mechanical rotating pressing rollers are used to squeeze these strips to facilitate better mechanical wet-bonding just before being manufacture.
5. The sliced strips are kept submerged for 48 hours to prevent drying out and keep the fibers soft.
6. The long strips of the whole stalk length were cut into three parts representing the top (40 cm below the flowering crown of the plant) , middle, and bottom area (10 cm over the red leaves of the stalks).
7. Papyrus sheets of each group of the strips are made separately into sheets by laying down two perpendicular overlapping layers of strips one atop the other.
8. They are fully dried under the press for 48 hours.

We can summarize the results of the effects of manufacturing process on the papyrus properties in the following points;

- 1- The harvested plants of June, July and August gave the best sheets of papyrus. And mechanical properties (Figs. 1-3)
- 2- Sheets must be made just soon after being harvested. From 3-7 hours is the preferable allowed time for manufacture. This helps easy peeling off the outer green bark and to avoid sticking it to the white inner pith. Manufacturing process should be done in a shadow area while stalks are still wet, or rewetting the stalks in case they exposed to drying conditions.
- 3- It is better to get the strips of the inner bark homogenous in thickness. Egyptian Papyrus Institute invented a tool for this purpose tensile tests and papyrus specimens were performed on screw-driven tensile testers that described previously. (Mecklenburg, and Tumosa, 1991)

It is obvious that the mechanical properties of papyrus different in one direction from another.

Tested samples in one direction show different data than the other. Although the papyrus samples contain two perpendicular layers, the gauges clamped two ends.

This means that one long strip is measured while other layer enhanced the maximum strength. Samples were subjected to the conditioning that is described in literature. Figure 1 shows the tensile results, stress/strain curve of the papyrus samples in both direction of the samples. Papyrus show very minor elasticity area under the curve, straight line, on the contrary to paper samples that shows more

elasticity. Papyrus shows high sensitivity towards the humidity. As the relative humidity increases, the moisture content increases consequently. It is known that papyrus may be considered a plant when explaining its physical properties. It is taking a few hours responding to a very little humidity change as seen in Fig. 4. This figure shows the influence of relative humidity change on the mechanical properties of papyrus sheets. The more humidity, the more strength and flexible sheets we have. This is due to the effect of water on the fibers as water molecules soften the inter-fiber bonds working as a plasticizers in-between. Figure 5 shows the maximum stress, breaking point, of papyrus at different relative humidity which represent dry conditions (16% RH), ambient conditions (45% RH) and humid conditions (86% RH).

Excluding the first inner-bark strips is probably due to its poor quality for either writing or painting purposes. First sheet shows coarse uneven surface and insufficient sticking in the overlapping edges when laying next to other good strips. Figure 1 summarizes some physical properties of papyrus sheets that manufactured versus harvesting time over almost 4 months.

In one contract, in the roman empire, there is an evidence that ascertain the results of the mechanical properties of papyrus. Better papyrus sheets were produced in summer. In one contract, the lessees pay the double rent for the period March to August, implying the production peaked in summer months.

Effects of pressing on the papyrus sheet quality

Pressing the freshly-made sheets of papyrus is very important in order to extract the starch and sugars in the strips and compressing the contents for more flexible and smooth papyrus sheets. To verify the effects of pressing on the papyrus quality, new sheets were made without being pressed. It is found that unpressed sheets required more time to dry than the air dried sheets.

In addition, the pressed sheets are less in thickness by 25% than the control sheets (non-pressed). Moreover, the color of the unpressed sheets are darker. These results proved the significance of pressing. The unpressed sheets are not valid for writing. Hammering of sheets resulted in good surface for writing as well as for painting, Fig. 6.

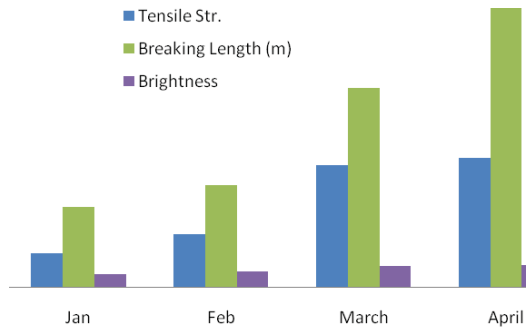


Fig. 1. Physical properties of papyrus versus time of harvesting.

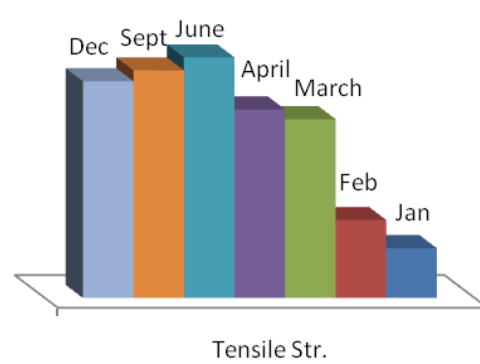


Fig. 2. Tensile strength versus harvesting time of papyrus.

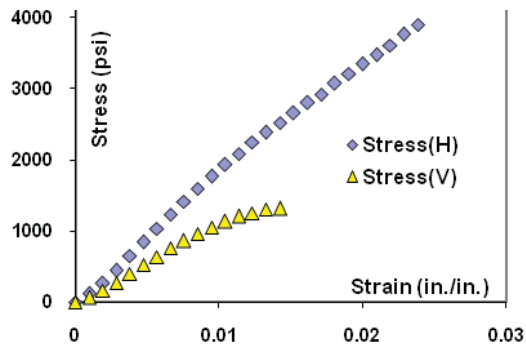


Fig. 3. Mechanical properties of papyrus represented as stress-strain.

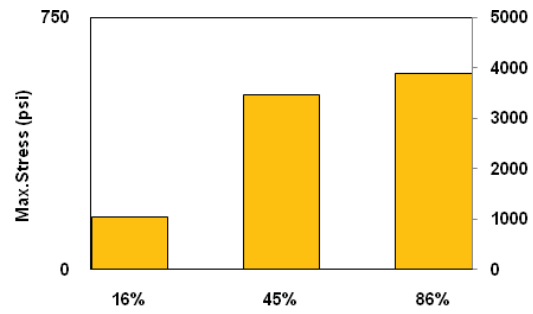


Fig. 4. Max. stress (breaking stress) of papyrus versus relative humidity.

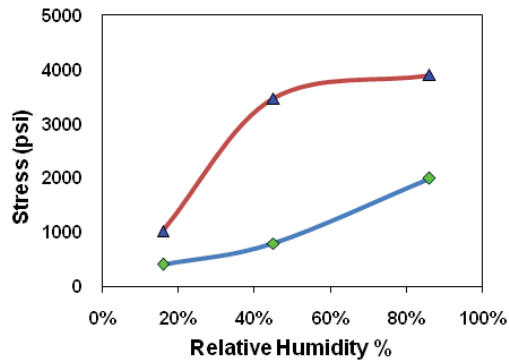


Fig. 5. Stress/strain for papyrus samples at 16%. 45% and 86% relative humidity.

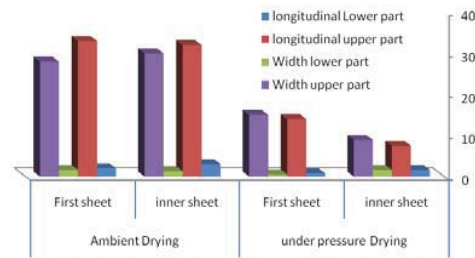


Fig. 6. Effects of drying techniques on shrinkage % on the lower and upper parts of papyrus sheets.

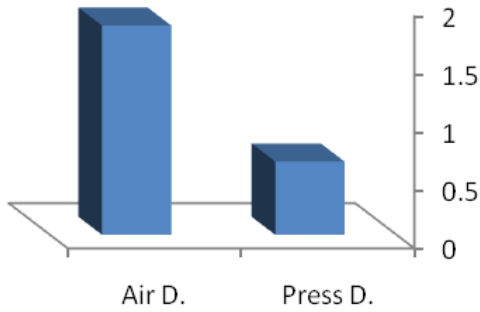


Fig. 7. Longitudinal contraction % first sheet.

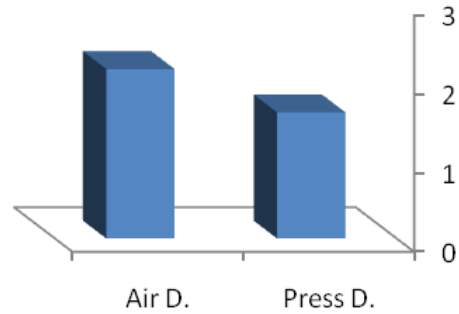


Fig. 8. Longitudinal contraction % inner sheet.

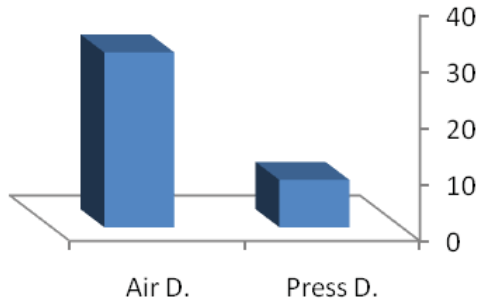


Fig. 9. Width contraction % inner sheet.

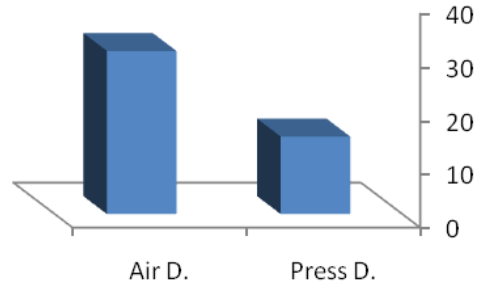
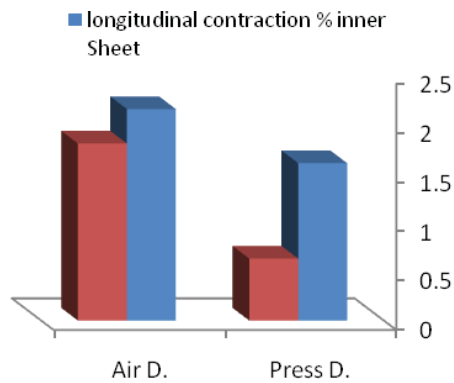


Fig. 10. Width contraction % first sheet.



. Fig. 11. Stress/strain for papyrus samples at 16%. 45% and 86% relative humidity.

In general, all sheets that are dried in open air condition (free drying) exposed more shrinkage than the under press drying sheets. Moreover, the inner sheets underwent more shrinkage than the first sheets. compare Figs. 7 to 9 for the shrinkage of both longitudinal and width contraction of inner sheets to the first sheets.

Contraction of the sheets that are dried in open air exposed more contraction than those which are dried under press. Identically, shrinkage in the width of the sheets is larger than shrinkage in longitudinal direction regardless of the drying technique. See Figs. 7-11 for comparison. Compare Figs. 7 and 8 to

Figs. 10 and 11. For overall view of contraction parameters see Fig. 6.

Fully soaking of the papyrus strips under water for 2-3 days prevents oxidation of the contents and discoloration of the sheets. This also resulted in good quality smooth and flexible sheets.

Chemical analysis versus mechanical properties

FTIR analysis of papyrus samples that were manufactured in January and February reveals more lignin-content than samples that are taken from the papyrus of the following months. Absorption of *c=c linkage* at 1630 cm⁻¹ and methoxyl at 1375 cm⁻¹ those are significant for lignin compounds are observed. In addition, absorption of 1735 cm⁻¹ and 1510 cm⁻¹ those are significant to *carbonyl* and *aldehydes* groups consequently were also existed. These groups resulted in decrease of inter-fiber bonding, this increases the lignin that lowering the cellulose and hemi-cellulose contents. This also resulted in the decrease of the mechanical properties of former sheets in parallel with an increase of brightness of the latter sheets. January samples were the worst not only in mechanical properties, maximum tensile, but also in brightness. As cellulose contents increases the hydrogen bonds increases which in turn improves the mechanical and optical properties; especially of April papyrus. Papyrus reaches its peak of growing up in June, July and August.

Conclusion

Papyrus physical properties are influenced by many aspects; harvesting time (i.e., age of the plant), plant species (*Cyprus papyrus*), stalk part (middle lower part is the best), processing techniques (pressing and drying method), the

location of the inner sheets. It is obvious that papyrus is a hygroscopic material which is sensitive to a minor relative humidity change which is proved when mechanical properties is measured in different range of RH. Chemical analysis may reveal the preservation status of the papyrus by measuring the decay results as possible, esp. when micro-chemical analytical methods are considered. No wonder that papyrus has been the substantial record of world cultures that was responsible for the transmission and preservation of thought since the dawn of ancient Egyptian civilization, circa 3200 BC, until the modern paper that was invented by Chinese has been commonly spread out all over the world.

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نتائج تجريبية عن الخصائص الفيزيائية للبردي

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الكلمات المفتاحية: البردي، الخصائص الفيزيائية، صناعة البردي، التحليل الكيميائي.

ملخص البحث. يتناول البحث نتائج تجريبية عن خصائص البردي الفيزيائية التي بررت استخدامه وتفوقه عبر الحضارات المختلفة. حيث يناقش كثافته ومعامل الانكماش والدرجة اللونية وذلك من خلال تصنيع شرائح من البردي الحديث ودراسة خصائصها المختلفة. كما تمت دراسة الخصائص الميكانيكية لشرائح البردي من خلال دراسة قوة الشد لفهم طبيعة وسلوك عينات شرائح ورق البردي نحو هذه الخاصية. وكانت هذه القياسات والتجارب سبباً في إزالة الغموض نحو تناول أسباب احتفاظ البردي بخصائصه الفيزيائية وفي حالة جيدة من الحفظ لآلاف السنين. فشرائح ورق البردي المصنعة من نبات حصد في شهر إبريل تمتاز بدرجة لونية أفتح وهي الأفضل بين كل الشرائح المصنعة في كل شهور السنة، ودعمت هذه النتائج القياسات المأخوذة بمطياف الأشعة تحت الحمراء. وتمت دراسة اختلاف الخصائص الفيزيائية لشرائح البردي عند اختلاف ظروف الحفظ من الرطوبة النسبية المحيطة وأعطت القياسات المختلفة عند درجات رطوبة نسبية مرونة تتزايد طردياً مع الرطوبة النسبية المحيطة. وقد أعطت هذه النتائج براهين علمية على براعة المصري القديم في اختيار الوقت المناسب لحصد النبات وصناعته وظروف الصناعة، مما يدل على براعة في التجريب والتطبيق والتجربة والخطأ وتعلم المصري القديم ودرايته وإتقانه لهذه الصناعة.