Evaluation the Egyptian banknotes durabilities profiles

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Introduction:

The severe deterioration levels exhibited by banknotes in circulation in Egypt triggered a research project into the causes.
Did the problem originate in the banknote paper, which is supplied by UK and French mill or in the conditions of importation? Did it originate in the printing inks of the dry offset, intaglio and relief printing processes? Or, did it originate in the security devices built into the banknote paper?
During this research project, hundreds of physical and optical tests were carried out in Milan at the SSCCP, the Research Institute of the Italian Pulp and Paper industry. The US dollar was used as the reference banknote, against which the various properties of the Egyptian 25pi and 1LE and 5LE notes were compared.
The Egyptian banknotes categorized into the piaster notes which are just the 5 pi, 10 pi and 50 pi notes, and the LE or Pound notes which come in denominations of: 1, 5, 20, 20, 50, 100 and 200 LE. A new 500 LE bill is being introduced

The security paper sheets for the Egyptian banknotes up to 1 LE, i.e. one pound, are imported from France, the rest is British made. All of the sheets are made from **100% cotton fibers** pulp paper with a zero kappa No. The fiber is derived from recycled rags. The security paper is shipped to Cairo as ready to print blank sheets.
It has the full range of built-in security components such as 3D watermarks, embedded security threads, Window holographic security threads, and fluorescent fibers.
In Cairo, the Egyptian banknotes sheets for 5 LE denomination up to the 200 LE note are printed with three different printing techniques; dry offset, intaglio and relief printing.

There are very few standards tackle with the end properties of the high durable permanent secured paper grades, which have been published by institutions like: IGT & FOGRA and by certified authorities like: ISO, DIN, ASTM, JIS, IEC or UNI. But there are no one of those authorities has published before specialized standards cover the durabilities mandatory requirements of the banknotes paper.

Research problem:

There is a major problem in that the circulating Egyptian banknotes exhibiting extreme levels of mechanical and optical deterioration. This includes the following characteristics:

- limp, slack and corroded edges,
- tears and holes, plastic
- weak faded inks

In addition to these common problems, there is the degradation arising from endless sources of soiling, such as oils, grease, dirts, chemicals… etc.

Research target:

The researchers set out to prove that these problems do not originate in the banknote paper and to demonstrate the quality of that paper in terms of mechanical and optical properties and durability. To do so, it was decided to test Egyptian banknote paper against a major currency with a world-wide circulation, the American Dollar and against the obligatory requirements of the specialized ASTM standards.

Research scope:

During the research project, dozens of laboratory tests were carried out on hundreds of banknotes samples to explore three main areas:

First, the research focused on the physical and optical properties of the two banknote groups, that is to say: folding and tensile strength, tear, burst and perforation strength; resistance to electrical conductivity and color.

Secondly, the deterioration of these physical and optical properties was evaluated in relation to 13 different chemical and environmental factors, the degree of deterioration being expressed in percentage. For example, the color fastness and fading resistance of the printing inks was evaluated in terms of the response to washing detergents, artificial sweat, high acidity and chloroform.

Lastly, depending on these percentages, the durability and longevity of Egyptian banknotes was evaluated and compared to that of the US dollar and also evaluated and compared to the ASTM specialized standards requirements (**ASTM**: the American Society of Tools & Machines). The ASTM D3290, D3458, D3208, D5634 & the ASTM D3460 requirements have been applied in this research.

Methodology and labs:

The research work utilized an experimental and analytical methodology and test were carried out at the labs of the Italian Pulp & Paper Research Institute (SSCCP) in Milan. www.sperimentalecarta.it.

The ambient circumstance:

Temperature was: 23+1"°c and the Relative humidity was: 50+1%.

The tests apparatus:

- Schopper folding endurance tester
- L&W tear strength tester / 4 samples method
- L&W burst strength tester / electronics type 2- CFS.
- Instron 1122 digital tensile strength & perforation resistance tester.
- Crock Meter / CM manual mechanical paper rubber.
- Electrolux – FOM 71 - CLS Standard automatic washer.
- LiEBHhere standard refrigerator.
- Digital densitometer.
- Digital Spectrophotometer.
- Bicasa BE.77 drying oven.
- Electrical pHmeter.
- Electronic stereo microscope.
- Xenotest white light & UV emission resistance tester with 8 steps blue control scales.
- 100 °c thermometer + boiling crystal balls.

The tests samples:

The selection of samples was circumscribed by several factors. In the first place, it was impossible to be blank -unprinted- banknote paper from the central banks or printing houses from testing purposes. It also became clear that all the US dollar denominations are printed on the same security paper which is made from (75% cotton + 25% linen). And finally, banknote papers are usually produced on special cylinder and Fourdrinier machines with no identified MD or CD. The test samples comprised uncirculated banknotes which were made in the US, the UK and France. These were: i) A $1 note which had just been issued; ii) An Egyptian 25 pi and LE1, or 1 pound note, made in France and newly issued; iii) An Egyptian LE5, or 5 pound note, made in the UK and newly issued.

Note: *digital optical analysis is the most up-to-date method of testing the durability of banknotes. The banknotes samples are subjected to an extremely fast rotating mechanism wherein they come into contact with small metal or polymer balls. The latter are either blank or are painted with the desired soiling or deterioration agent. The balls simulate human fingers and the very high speed simulates the wear caused by years of normal circulation - the accelerated aging test utilizes high temperatures to simulate similar conditions.*
Having gone through the rotating procedure, the banknote paper is subjected to video digital analysis which focuses on:

- *The features of mechanical deterioration, that is to say: corroded edges, holes, slits, and so on; and*

— *The features of optical deterioration features , such as ink fading and ink loss inks losses, soiling ratios. Sure, etc.*

Digital optical analysis provides the most realistic simulation of the wear and tear that takes place during the life cycle of a circulating banknote.

Test results:

- **Paper pulp composition and optical properties results:**

Banknotes samples / Pulp stuff & optical properties	measurement unit	1 USD	Egyptian banknotes 25 pi.	Egyptian banknotes 1 L.E.	Egyptian banknotes 5 L.E.
Pulp stuff	-----	75% cotton + 25% linen	100% cotton	100% cotton	100% cotton
Kappa No.	-----	zero	zero	zero	zero
pH	----	7.4	7.1	7.1	7.6
$CaCO_3$ weight ratio	%	4	2.5	2.25	3
Moisture content	%	2.2	3	3.1	3.3
Opacity	%	93	85	90	92
ISO Brightness	%	90	87	88	94

Table 1:

The pulp composition & optical properties of Egyptian and US banknote samples

- Physical strength properties results:

The results of hundreds measurements and calculated percentages are summarized in tables 2,3 and 4.
Table 2 presents the findings on the various physical strength properties such as: folding and tensile; tear and burst; perforation strength and resistance to electrical conductivity.
During the testing of the banknotes, care was taken to avoid the areas of the watermarks, full embedded security threads & window holographic security threads.

Paper banknotes Samples / Basic & strength properties	measurement unit	1 USD	Egyptian banknotes		
			25 pi.	1 L.E.	5 L.E.
Basis weight	$g\backslash m^2$	96.6	86.8	86.8	88.96
Thickness	micron	103	115	119	116
Folding endurance (MD)	double folds	7200	4100	3052	4450
Folding endurance (CD)	double folds	7761	4360	3165	4572
Tensile strength(MD)	KN/m	7.64	7.41	8.26	8.63
Elongation percentage (MD)	%	5.3	6.35	6.5	7.4
Tensile strength (CD)	KN/m	4.574	4.01	4.18	4.25
Elongation percentage (CD)	%	8.02	9.07	7	8.82
Tear strength (MD)	mN	720	650	724	658
Tear strength (CD)	mN	771	797	1019	766
Burst strength	KPa	338	458.64	450	460.6
Perforation strength	N	41,54	39,28	61,56	62,1
Electrical conductivity resistance	Ohm	2,45× E10	6×E10	4,3×E11	6,15× E11

Table 2:
The physical basic & strength properties of Egyptian and US banknote samples

Figure "1": Measuring the USD basis weight (left) & thickness (right)

The results show that Egyptian banknotes samples surpassed the US samples in tensile, tear, burst and perforation strength and in resistance to electrical conductivity.
However, the US samples showed superior folding strength, the most important and critical physical property for the longevity of banknote paper.

- Mechanical durabilities results:

Table 3 presents the findings on the deterioration of strength properties, when the banknote samples were subjected to chemical and environmental stress. The latter includes acidity and alkalinity levels of pH1.5 and 12.5 respectively; and elevated temperatures of 105º C which simulate accelerated aging.
The Egyptian banknotes samples were superior in their retention of folding and tear strength under chemical and environmental pressures. The US samples were superior in the retention of tensile and burst strength and in their resistance to the accelerated aging process.

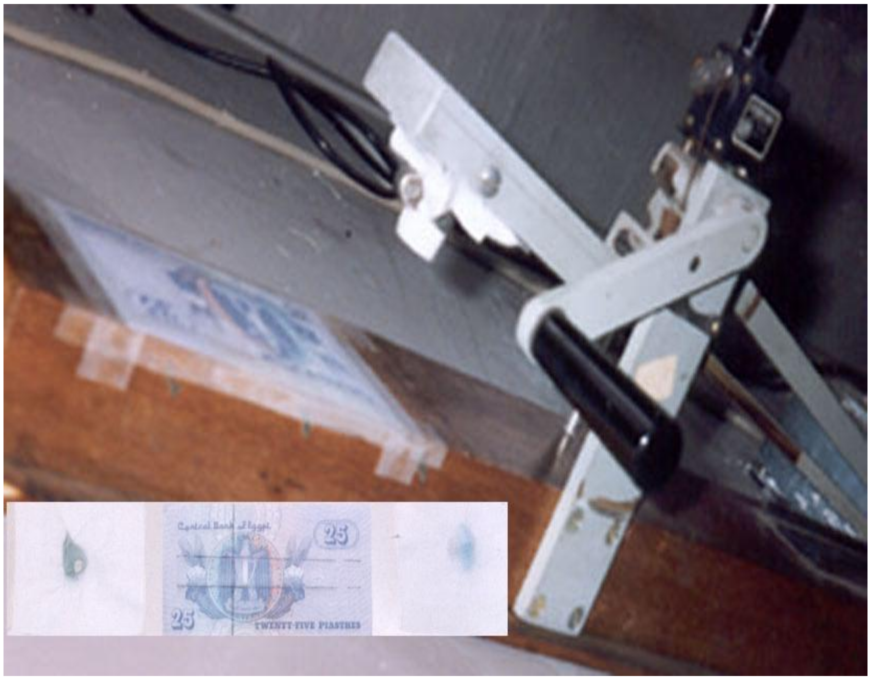

Figure "2": The Egyptian 25Pi. paper banknote while mechanical rubbing

Figure "3": The cotton covered plastic rub head on the 1 USD banknote

Figure "4": The original embossing rough intaglio printed lines on the 1 USD banknote

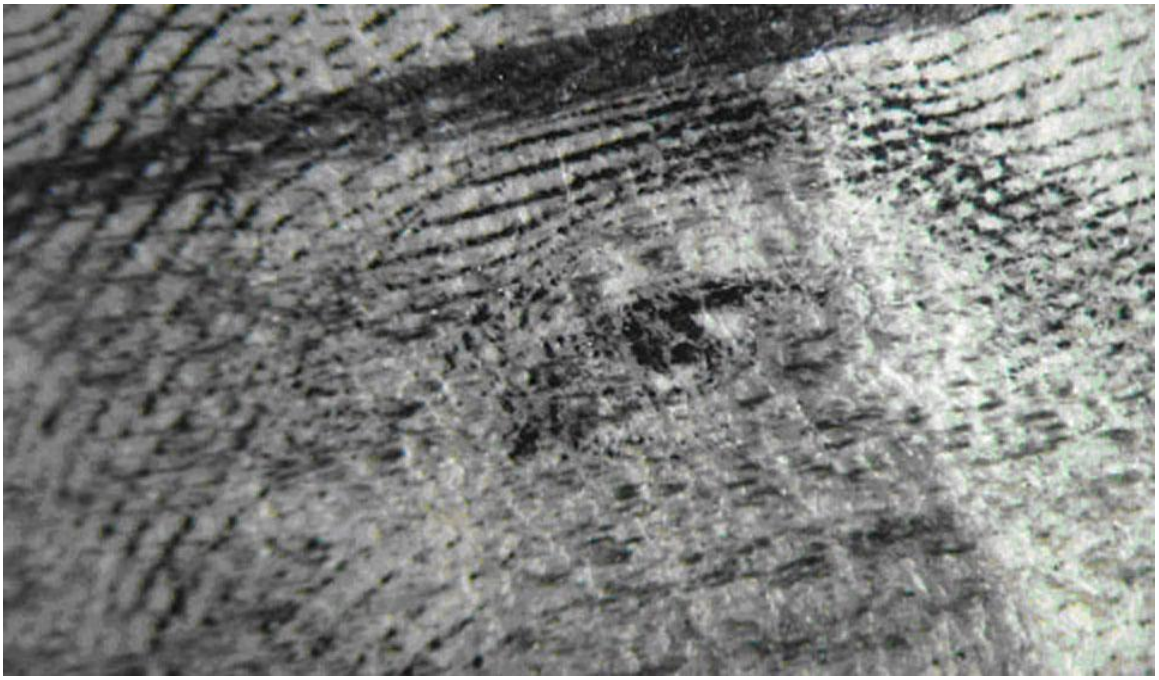

Figure "5": The rubbed intaglio printed lines on the 1 USD banknote

Deteriorations factors	Exposure period	Folding Strength deteriorations				Tensile Strength deteriorations				Tear Strength deteriorations				Burst Strength deteriorations			
		1 USD	Egyptian banknotes			1 USD	Egyptian banknotes			1 USD	Egyptian banknotes			1 USD	Egyptian banknotes		
			25 pi	1 L.E.	5 L.E.		25 Pi.	1 L.E.	5 L.E.		25 Pi.	1 L.E.	5 L.E.		25 Pi.	1 L.E.	5 L.E.
High acidity (pH = 1,5)	30 minutes	69%	65%	25%	36%	2%	5%	3%	10%	11%	16%	10%	3%	26%	53%	10%	7%
High alkality (pH = 12,3)	30 minutes	76%	57%	14%	36%	29%	6%	11%	8%	4%	4%	1%	2%	7%	23%	19%	1%
Artificial sweat	6 days	47%	18%	10%	4%	10%	5%	3%	13%	19%	15%	10%	1%	34%	47%	12%	2%
Boiled water	30 minutes	63%	75%	42%	44%	5%	4%	4%	47%	2%	3%	3%	5%	5%	20%	28%	11%
Standard automatic washing (programme:2A)	5 steps in 25 minutes	83%	64%	43%	55%	20%	4%	19%	17%	1%	1%	4%	2%	1%	5%	10%	5%
- 20 °C Temperature	10 days	40%	5%	3%	16%	24%	10%	56%	49%	2%	10%	2%	7%	6%	3%	1%	3%
Accelerated aging (90°C & 50 % RH)	12 days	16.4%	19.14%	13.7%	17%	-	-	-	-	-	-	-	-	-	-	-	-

Table 3:

The Strength physical properties deteriorations percentages

- **Printing inks durabilities results:**

Table 4 presents the findings on the ink fading factor which was evaluated in relation to the original density of the main portrait on the banknote. The banknote samples were exposed to high acidity and alkalinity, to mechanical rubbing and white light – to simulate daylight and to acetone and chloroform. Their response is expressed in the monochrome fading percentages of the main portraits.

Ink fadness Factors	**Exposure Period**	**1 USD**	**Egyptian banknotes**		
			25 Pi.	**1 L.E.**	**5 L.E.**
The main portrait (or vignette) -original density	-	*0.83*	*0.6*	*0.81*	*0.85*
Standard automatic washing detergent	**25 minutes**	Zero%	Zero%	Zero%	9.6%
Artificial Sweat	**6 days**	0.4%	0.7%	Zero%	2.4%
High acidity "pH=1.5"	**30 minutes**	1%	4.9%	Zero%	7.1%
High alkality "pH=12.3"	**30 minutes**	12%	10.9%	4.1%	7%
Acetone	**5 days**	Zero%	Zero%	Zero%	Zero%
Chloroform	**10 days**	Zero%	24.4%	13.9%	13.1%
H_2O_2	**3 days**	Zero%	Zero%	Zero%	Zero%
$NacLO_2$	**24 hours**	51.8%	13.6%	16%	15.9%
Mechanical rubbing	**999 times**	51.3%	17.6%	10.37%	3.9%
Artificial daylight "white light"	**74 hours**	11.3%	10.7%	2.46%	3.19%

Table 4:

The main vignettes & portraits "monochrome" fadness percentages

The results showed the Egyptian banknotes to be superior in terms of the fading resistance under NacLO2 exposure, high alkality, mechanical rubbing and artificial daylight.
The printing inks on the US samples showed superior fading resistance when subjected washing detergents, artificial sweat, high acidity and chloroform.

Figure "6": The Egyptian banknotes & the USD$_s$ after (10 days) chloroform bleeding

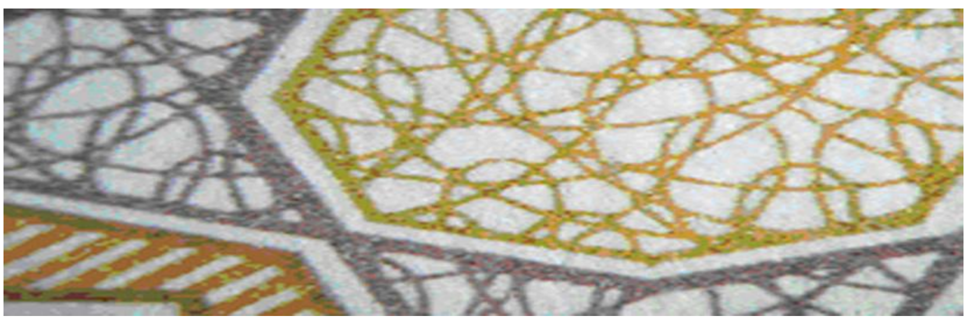

Figure "7": The brown & yellow dry offset printed lines on the Egyptian 1 pound Banknote

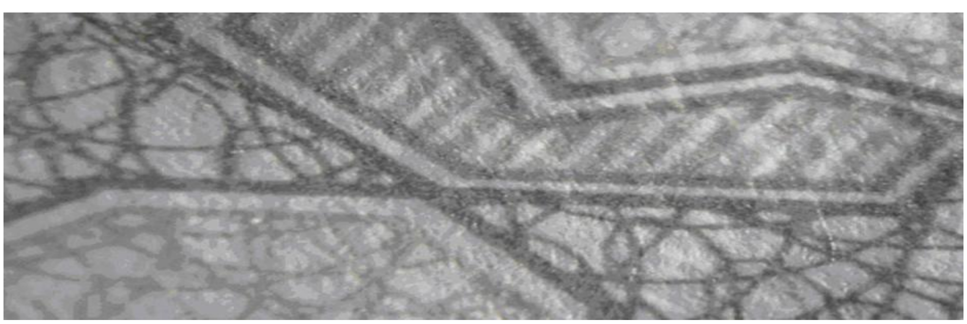

Figure "8": The Same lines after (10 days) chloroform bleeding

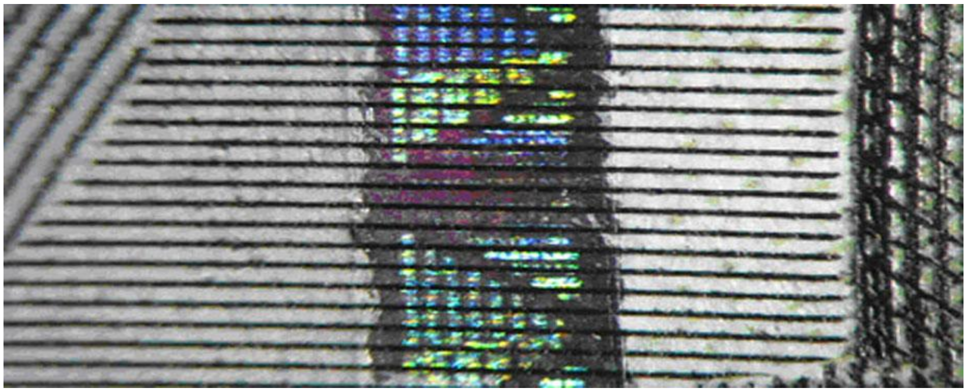

Figure "9": The window holographic security thread of the Egyptian 5 pounds banknote

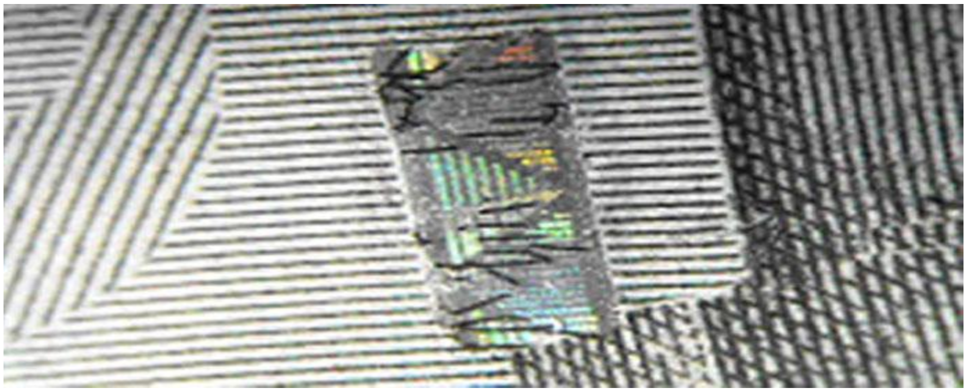

Figure "10": The same thread after (10 days) chloroform exposure

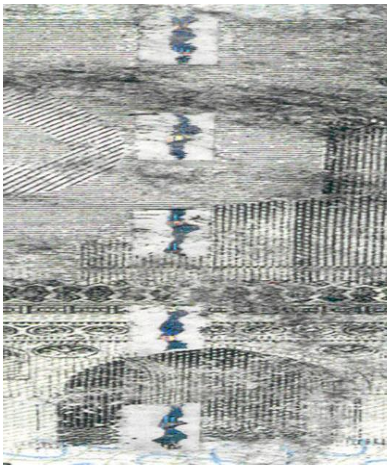

Figure "11": And after (1 day) NacLO2 exposure

Figure "12": Left: 1 USD, Middle: Egyptian 5 L.E. & Right: Egyptian 1 L.E. banknotes bleeding intaglio inks, after (1 day) NacLO2 exposure

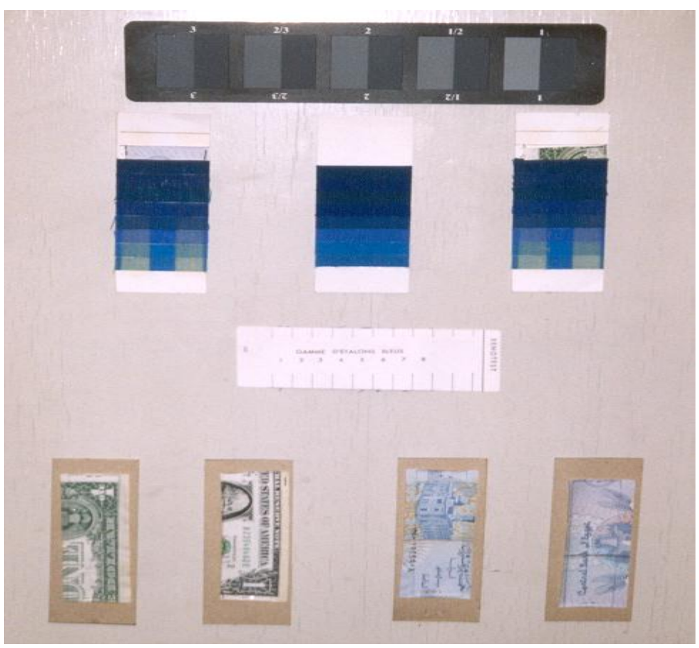

Figure "13": The USDs & Egyptian banknotes samples after 74 hours artificial day (white) light exposure resistance test

- **Evaluation the conformance of the Egyptian paper banknotes durability profiles to the ASTM standards requirements:**

The ASTM **D3290** “Standard specification for bonds & ledger papers for permanent records” standard has been issued in 2000; it covers the ledger and bond paper grades which expected to have maximum lives (more than 100 years) with minimum mechanical & optical deterioration ratios.

Also the ASTM **D3208** “Standard specification for Manifold papers for permanent records” standard has been issued in 2000 but it covers the manifold papers which used for preparing the permanent records & documents.

On the same way ASTM **D5634** “Standard guide for permanent and durable offset & book papers” standard has been issued in 2001 and it covers the offset paper grades which used for printing permanent records & books.

Finally the ASTM **D3458** “Standard specification for copies from office copying machines for permanent records” standard has been issued in 2000, while The ASTM **D3460** “Standard specification for white watermarked and un-watermarked bond, reprographic & laser printer cut sized office papers” standard has been issued in 2007; they both cover the copies produced from the office analogue or digital printers or copiers which expected to have maximum span lives.

Properties & durabilities profiles		**Egyptian banknotes (25pi.\ 1L.E.\ 5L.E.)** Average values	**ASTM D3290-00 requirements**	**The conformance**	**ASTM D3458-00 requirements**	**The conformance**	**ASTM D3208-00 requirements**	**The conformance**	**ASTM D5634-01 requirements**	**The conformance**	**ASTM D3460-07 requirements**	**The conformance**
Pulp composition	**Pulp stuff**	100% cotton fibers	Must be cotton, linen or chemical bleached fibers	√	Must be cotton, linen or chemical bleached fibers	√	Must be cotton, linen or chemical bleached fibers	√	Must be cotton, linen or chemical bleached fibers	√	25% at least of pulp weight Must be of cotton, the rest must be chemical bleached fibers	√
	Kappa No.	zero	Must be < 5	√	Must be < 5	√	Must be < 5	√	Must be < 5	√	Must be = zero	√
	pH	7.2	Must = (6.5:7.5)	√	Must = (6.5:8 .5)	√	Must = (6.5:7.5)	√	Must be > 7	√	Must be > 4.7	√
	CaCO3 weight ratio	5%	Must be > 2%	√	Must be > 2%	√	Must be > 2%	√	Must be > 2%	√	Not specified	√
Physical properties	**Basis weight ($g\backslash m^2$)**	87.52	Must = (57:120)	√	Must = (60:90)	√	Must = (31:36)	√	Not specified	√	Must be > 75	√
	Thickness (micron)	116.6	Must = (97:145) for (80:90) $g\backslash m^2$ grades	√	Not specified	√	Must = (46:61)	√	Not specified	√	Must be > 114	√
	Tearing strength MD & CD (mN)	MD = 677 CD = 860	Must be > 200, MD or CD. For (80:90) $g\backslash m^2$ grades	√	Must = (295:490)	√	Must be > 177, MD or CD.	√	Must be > 528, (MD) & Must be > 569, (CD)	√	Not specified	√
	Folding endurance MD & CD (double folds)	MD =3867 CD = 4032	Not specified	√	Must be > 200, MD or CD.	√	Must be > 200, MD or CD.	√	Not specified	√	Not specified	√

	Tensile strength MD & CD (kN\m)	MD = 8.1 CD = 4.14	Not specified	√	Not specified	√	Not specified	√	Must be > 5.15 (MD), elongation > 1.53% & Must be > 2.7 (CD), elongation > 3.73%	√	Not specified	√
	Burst strength (kPa)	456	Not specified	√	Not specified	√	Not specified	√	Must be > 212.5	√	Must be > 172	√
	Moisture content (%)	3.13	Not specified	√	Not specified	√	Not specified	√	Not specified	√	Must = (3.5:6.2)	√
Optical properties	**Opacity (%)**	89	Must be > 85, for (80:90) g\m^2 grades	√	Must be > 85	√	Not specified	√	Not specified	√	Not specified	√
	ISO Brightness (%)	89.6	Must be > 75	√	Not specified	√	Must be > 75	√	Not specified	√	Must be > 86	√
Artificial aging resistance		The deterioration of the folding (MD) strength profile after **12** days (**90**˚C & **50** % RH) = 16.6 %	The deterioration of any mechanical strength profile after **12** dayss (**90**˚C & **50** % RH) must be < 30%	√	The deterioration of any mechanical strength profile after **12** dayss (**90**˚C & **50** % RH) must be < 30%	√	Not specified	√	The deterioration of any mechanical strength profile after **12** dayss (**90**˚C & **50** % RH) must be < 20%	√	Not specified	√

Table 4:

The Egyptian paper banknotes conformance evaluation with the ASTM standards requirements

The results analysis:

1- The **Egyptian** paper banknotes samples have surpassed the US banknote in terms of:
i) Tensile, tear, burst and perforation strength and in resistance to electrical conductivity.
ii) The retention of folding and tear strength under various chemical environmental deterioration factors.
iii) Ink fading resistance under exposure to high alkality, NacLO2, mechanical rubbing and artificial daylight.

2- The **US** banknote samples excelled in:
i) Folding strength, the most important and critical physical property for the longevity of banknote paper.
ii) The retention of tensile and burst strength retention under various chemical and environmental deterioration factors; and, accelerated aging resistance.
iii) Ink fading resistance under exposure to washing detergents, artificial sweat, high acidity and chloroform.

3- The Egyptian paper banknotes durability & properties profiles **have conformed to all** the mandatory requirements of the ASTM specialized standards (**D3290**, **D3458**, **D3208**, **D5634** and **D3460**).

Findings and conclusions:

The research project found that many of the Egyptian banknote samples were superior to the US samples in terms of physical strength properties and durability parameters.
That clearly proves the banknote papers used for Egyptian currency, is of normal and good reliability in terms of strength and optical properties and longevity. And, these properties are not impaired by the process of importation.
It is also clear that the high levels of mechanical and optical deterioration which characterize banknote which are in circulation in Egypt do not stem from the components of the banknotes, that is to say, paper, inks and security elements.
The high levels of deterioration are therefore attributed to misuse and miscirculation and the inadequate respect shown to Egyptian banknotes. It is now the responsibility of the Egyptian social scientists to address this problem and to bring about a change in the behavior bad habits which are causing huge economical losses and hygiene dangers.

The research figures:

The evaluation of the paper properties under stress is shown in figures **1** to **4**.
Figure **l** shows the measurement of the USD_s basic physical properties.
Figure **2** shows an Egyptian 25 Pi banknote during mechanical rubbing while in figure **3**, the cotton covered plastic rub head is being applied to a $1 banknote. Figure **4** shows the original embossing and rough intaglio printed lines on the $1 banknote while the rubbed intaglio printed lines are shown in figure **5**.

Figures **6**, **7** & **8** show the impact of chloroform bleeding on the Egyptian & American banknotes.
Figure **7** shows the brown and yellow dry offset printed lines of the pristine note, while figure **8** shows the same lines after 10 days of chloroform bleeding.
Figures **9** and **10** show the reaction of the window holographic security thread to chloroform exposure. In this case the sample is an Egyptian 5 Pound banknote, LE5.
Figure **9** shows the pristine note, while Figure **10** shows the same thread after 10 days of chloroform exposure.
Figures **11** and **12** show the impact of NacLO2 exposure on Egyptian and US banknotes.
Figure **11** shows the Egyptian LE5 note after 1 day of exposure, while figure **12** shows the bleeding intaglio inks after 1 day of exposure.
Figure **13** shows the banknotes optical deterioration resistance test.

The research abbreviations:

The abbreviations	The definitions
IGT	Institute of Graphic Techniques
FOGRA	Foundation Of Graphic Research Association
ISO	International Standardization Organization
DIN	German Standards
ASTM	American Society for Tools & Machines
JIS	Japanese Industrial Standards
UNI	Italian Standards
MD	Paper fibers Machine Direction
CD	Paper fibers Cross Direction
pH	Hydrogen Ion Concentration
Kappa number	The lignin weight ratio in the paper pulp
Wet litho offset	Indirect printing from plain plates using organic dampening solution
Dry offset	Indirect printing from relief flexible polymer plates without using organic dampening solution
Intaglio	Direct printing from engraved metal cylinders

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