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Scientific article

Measurement of thermo-elastic behavior of some paper substrates and thermal behavior of blanket to analyze Offset Printing system

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Abstract:

In offset printing, the uses of water in the fountain solution have manifold applications. The primary function is to differentiate between image area and non-image. One of the secondary functions is to cool down the adjacent cylinder surfaces which in case of waterless offset are provided by water cooling jacket. When the water is transferred from blanket to the paper surface, due to moisture absorption the paper increases in size in micron level. This may create registration problem. There are already few mechanisms are present to overcome this problem. To calculate the actual expansion of paper due to moisture change and thermal differences in paper as well as expansion of the blanket due to the temperature differences because of high speed of offset machine and friction between cylinders, the different thermal properties of the paper and blanket such as coefficient of linear expansion, thermal conductivity, specific heat and elastic properties such as poisson's ratio, modulus of elasticity, etc. need to be measured. The present investigations have been confined to the effect of heat on the paper as well as blanket surface which can affect the print quality. The measurement of some of the thermal and elastic properties of the two different types of paper and thermal properties of blanket has been measured. It has been found that thermal conductivity and specific heat of the paper usually have decreasing tendency with increasing temperature. The thermal conductivity and specific heat of the blanket also have a decreasing tendency with increasing temperature. The co-efficient of thermal expansion of the paper samples increases rapidly with increase in temperature in the sub-zero temperature range followed by it remains either constant or decreases slowly depending on the type of paper.

Keywords:

Offset Printing, Paper, Blanket, Coefficient of linear expansion, Thermal Conductivity, Specific Heat.

1. Introduction

Offset Printing process is used for commercial printing, newspaper printing [1] and packaging purposes. This process is used for huge volume of production with optimum quality in short duration of time and low cost. So high speed machineries are used to obtain print in short duration. In cylinder to cylinder printing when two dissimilar cylinder surfaces are in contact in high speed offset printing machine, printing quality such as dots, lines, text etc. may be affected due to the thermo-elastic stress developed at the nip of the two cylinders at the time print transfer from the blanket to the substrates such as papers, boards etc. So, careful measurement of thermo-elastic properties of blanket and paper need to be assessed.

In Offset Printing, the paper substrate passes between the blanket and impression cylinder to transfer inked image from blanket to the substrate in order to get printed by the pressure of both the cylinders (Figure 1) [2] . In high speed offset printing machine (particularly web offset), a significant amount of heat generates on blanket cylinder due to friction [3]. When the paper passes between blanket and impression cylinder, it gets direct contact to the heated surface of the blanket. The present investigations have been confined to the effect of heat on the paper as well as blanket surface which can affect the print quality. The top surface of the paper gets direct contact with the heated blanket. It has been found that the heat flow from top surface of the paper to the opposite surface of the paper is bare minimum due to its low thermal conductivity and specific heat. This result in a temperature difference between the two surfaces of paper and will develop thermal stress within the paper due to thermal expansion. If the thermal stress in combination with tensile stress exerted during printing is beyond the elastic limit of the paper, this will create permanent deformation of the paper. So the measurements of thermal as well as elastic properties of paper may be helpful to control the print quality on the paper.

Earlier studies in this domain on effect of blanket roller deformation on print qualities in gravure offset print method [4] discusses about the effect of blanket roller deformation on print qualities. These study establishes that in the gravure-offset printing process, deviation of the printed pattern, changes in dot gain and changes in position of the patterns caused by nip deformation of rubber blanket, is affected by printing loading and friction. A local pattern distortion occurs due to non-uniform friction condition caused by partial patterned zone. Evaluation of nip pressure profile and analysis of heat transfer in soft nip calendar has been conducted by Sayong lee et.al. [5]. Some other researches in the related field have been conducted by Yang L., (2020) [6] and Gupta N., Kanth N., (March 2020) [7].

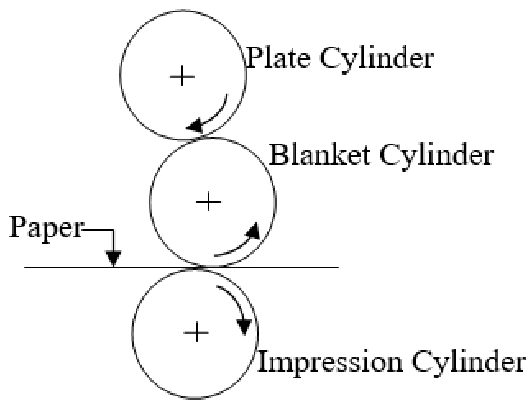

Figure 1 *Schematic diagram of Offset Printing process.*

2. Materials and Methods

Measurements of the different properties of coated paper and blanket are confined to the measurements of elastic and thermal properties. Two commercially available coated papers (Make: Emami Paper Mills, India) have been tested. The Thickness of the papers are 0.068mm and 0.079mm consecutively and GSM (gram per square meter) are 71.58 and 81.11 consecutively. A commercially available 4-ply non-compressible conventional offset rubber blanket (Brand: Cow) has been taken into consideration for measurement. While testing, the machine direction has been considered for the measurement of mechanical and thermal properties of paper as in web offset printing the grain direction is parallel to the movement of the web. Relative humidity and atmospheric temperature have been measured using dry and wet bulb thermometer. Elastic properties are limited to the measurements of modulus of elasticity and Poisson’s ratio for paper. Thermal properties are limited to thermal conductivity, specific heat for both paper & blanket and co-efficient of linear expansion for paper.

2.1 Modulus of Elasticity

The resistance type strain gauge (Model No.: SI 310, Make: Syscon India Ltd.) with the resistance of 350Ω and 2.0 gauge factor, is utilized for measuring the paper's modulus of elasticity. Firstly, the strain gauge is affixed to the sample surface using a commercial adhesive. The sample-strain gauge combination is exposed to various tensile stresses, and a strain indicator (Model No.: SI-28MS, Make: Syscon India Ltd.) measures the resulting strain values. Figure 2 schematically illustrates the experimental setup [8] for these measurements. Approximately 300 data from two different paper samples are utilized to measure the modulus of elasticity of the paper. The standard deviation for the results (see Table1) are so wide as paper is hygroscopic in nature and as the atmospheric conditions vary during experimentation for long period of time and the data has been taken in different atmospheric conditions, so the moisture content will vary for same type of sample in different relative humidity condition. Table1 shows the mean values of the modulus of elasticity

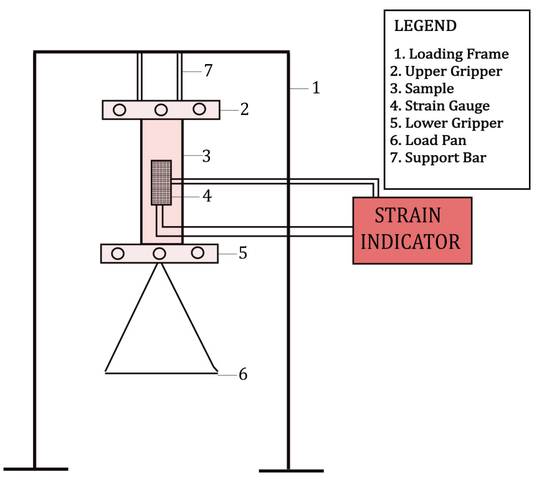

Figure 2 *Measurement of modulus of elasticity.*

2.2 Poisson's ratio

A travelling microscope is used to measure the Poisson's ratio of different paper samples. The surface of the sample with the drawn grids of 4.0 mm X 10 mm is subjected to various loads in order to measure the Poisson's ratio. Moreover vertical and longitudinal strains are also measured by travelling microscope. The same experimental set up as shown in Figure2 is used for this measurement. Approximately 150 data for each sample is taken for this measurement purpose. Table1 shows the mean value of Poisson's ratio measurement.

2.3 Thermal conductivity

A standard test is followed to measure the thermal conductivity (ASTM C-177-45) of sample by placing it inside a Guarded Plate Heat Conductivity meter (Model No.: DTI-12, Make: S. C. Dey & Co. Ltd., India).The sample is heated over a certain temperature range and at different ambient conditions. The temperatures on both sides of samples are measured using thermocouples [9]. The following equation [10] is utilized to calculate the thermal conductivity of the sample:

$$Q = \frac{kA(\Theta_1 - \Theta_2)}{\Delta t} \quad (1)$$

Where, Q= amount of heat in Watt, A= area of the sample in m2, K= thermal conductivity in W/m K, $(\theta 1-\theta 2)$= temperature difference between the two surfaces of the sample in Kelvin, and Δt= thickness of the sample in meter. The experimental set up is shown in Figure 3. Approx 150 data for each sample is considered for the thermal conductivity measurement purpose. Table2 shows the mean value obtained from the measurement.

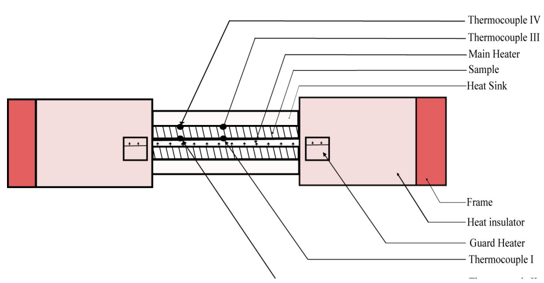

Figure 3 *Schematic diagram for the measurement of thermal conductivity of different paper and blanket samples.*

2.4 Specific Heat

The specific heat is determined using a guard plate heat conductivity unit. When one side of a sample is heated, the adjacent layer to the heater absorbs some of the heat, causing its temperature to rise. The remaining heat is lost through radiation from the surface and convection through the air. The rest of the heat available is then transferred into the adjacent layer, causing its temperature to increase. The instrument is designed to minimize the losses due to radiation and convection [9]. The specific heat is calculated using the following equation [11]:

$$C = \frac{Q}{\rho \frac{d\Theta}{dt}} \quad (2)$$

Where, C=specific heat of the sample in kJ/kg K, ρ=density of the sample in kg/m3, dθ = temperature changes of the sample layer in Kelvin and dt= thickness of the sample in meter. Approx 150 data for each sample and standard deviation is considered for the specific heat measurement purpose. Table2 shows the mean value of specific heat obtained from the measurement.

2.5 Coefficient of Linear Expansion

The coefficients of linear expansion for the samples are measured using a resistance-type strain gauge (with a gauge factor of 2.0 and resistance of 350Ω). To measure the coefficient of linear expansion, the strain gauge is affixed to the sample's surface using commercial adhesive. The sample-strain gauge combination is then enclosed in a closed chamber, where the temperature is varied over a wide range, from negative to positive temperatures (-600C to 280C), by applying liquid nitrogen The surface temperature of the sample is measured using Hewlett Packard Data Acquisition System (Model: 34970A, Hanover Street, Palo Alto, CA-94304-1185, USA) through thermocouple. The Coefficient of Linear Expansion is calculated using the following equation [11]:

$$\alpha' = \frac{\frac{\delta l}{l}}{(\Theta_1 - \Theta_0)} \quad (3)$$

Where, α' =coefficient of linear expansion of the sample in/K, l= initial length in m, $(\Theta_1 - \Theta_0)$= temperature difference between initial and final of the sample in Kelvin and δl = change in length in µm.

The strain gauge is connected to strain indicator by wheatstone bridge connection. The initial calibration is done by zero setting the strain value. $\delta l/l$ has been measured by strain indicator and the temperature difference of the sample surface has been measured by Hewlett Packard Data Acquisition System using K-type thermocouple.

Figure 4 shows the experimental set up for this kind of measurement. The experimental arrangement for such measurement has been published earlier [12]. About 150 data of each samples is considered for this experiment. Table2 shows the mean value obtained from the measurement.

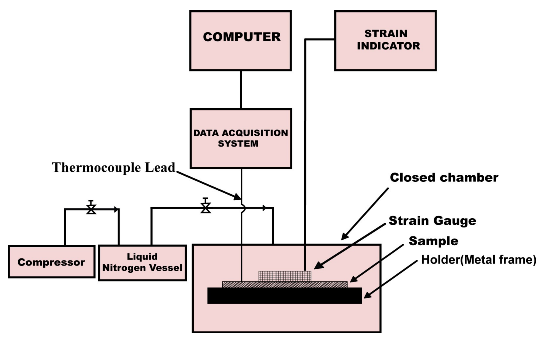

Figure 4 *Schematic diagram for the measurement of Coefficient of linear expansion of paper samples.*

3. Results

The measurements have been conducted on two coated paper samples and one blanket sample. Table1 shows the results of the measurements of mechanical properties of the samples. Table2 shows the results for the measurements of thermal properties of the samples.

It has been observed from Table 2 that the thermal conductivity of paper sample1 is less as compared to paper sample2. And

2.4 Specific Heat

specific heat of paper sample 1 is little more in comparison to paper sample 2. The thermal conductivity of blanket is much higher than that of both the paper samples.

It has been found from Table 1 that the modulus of elasticity of paper sample2 is higher than that of paper sample1 and the poison's ratio of paper sample1 is higher than that of paper sample2.

Table1 *Mechanical properties of paper samples.*

Sample no.	GSM	Thick-ness (mm)	Modu-lus of Elastic-ity*	Pois-son's Ra-tio
Paper sample 1	71.58	0.068	5.015 ± 1.245	0.6025
Paper sample 2	81.11	0.079	5.849 ± 2.247	0.4178

*(Gpa) (in grain direction)

Table2 *Thermal properties of Paper and Blanket samples.*

Sample no.	Density (Kg/m3)	Thickness (mm)	Thermal Con-ductivity (W/m K) X 10-2	Specific Heat (kJ/ kg. K) X 10-2	Coefficient of thermal Expansion (µm/m. K)
Paper sample 1	1052.647	0.068	0.1529± 0.012	0.0189 ± 0.006	3.2807 ± 3.29
Paper sample 2	1026.734	0.079	0.2635± 0.023	0.01804± 0.002	0.7968±0.133
Blanket sample	836.97	2.47	15.855 ± 2.41	0.1918 ± 0.039	-

Figure 5, 6 shows the variation of coefficient of linear expansion with temperature plot of different samples at different atmospheric conditions. Figure 7, 8 shows the variation of the specific heat of blanket and paper samples respectively at different atmospheric conditions. Figure 9 shows the stress-strain curve of paper samples at different atmospheric conditions. Figure 10, 11 shows the variation of the thermal conductivity with temperature of blanket and paper samples respectively at different atmospheric conditions.

4. Analysis

It has been observed from Table 2 that the thermal conductivity of blanket is much higher than that of paper samples. This implies that more heat will be conducted through the blanket into the blanket cylinder body (metallic), but a part of the heat which will be transmitted to the paper surface in contact with the blanket. This heat remains on the same side of the paper samples due to low conductivity and specific heat creating a stress difference between the two surfaces of the paper. This will affect the reproduction of dots and fine lines due to differential expansion of the paper with respect to two sides of paper surfaces.

It has also been found that the thermal conductivity of Paper Sample 1 is less than that of Paper Sample 2 and the Coefficient of thermal expansion of Paper Sample 1 is more than that of Paper Sample 2. Since the thermal Conductivity of Paper Sample 1 is less than that of Paper Sample 2, and Specific heat of Paper Sample 1 is higher than the Specific heat of Paper Sample 2, more heat is retained within the Paper Sample 1 and as a result, the Coefficient of thermal expansion of Paper Sample 1 is higher than that of Paper Sample 2.

This will affect the reproduction of images on Paper Sample 1 in comparison with Paper Sample 2 due to difference in expansion of the two sides of the Paper Samples while printing.

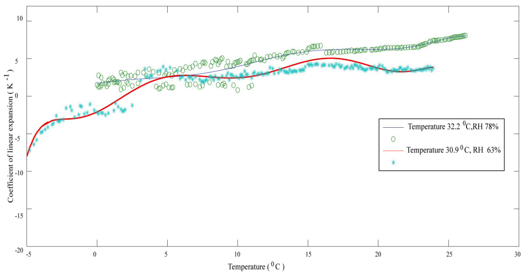

Figure 5 *Variation of coefficient of linear expansion of paper sample 1 at different atmospheric conditions.*

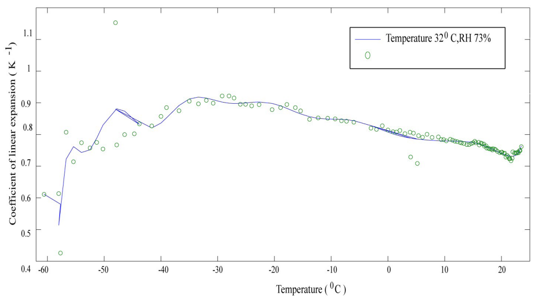

Figure 6 V*ariation of coefficient of linear expansion of paper sample 2.*

Figure 5 and 6 show the coefficient of linear expansion for both the paper samples at different atmospheric conditions. For paper sample 1, the coefficient of linear expansion increases with increasing temperature and is at its maximum in the range of 23 −28 °C. This may be due to different polymeric cellulosic fiber, fillers and loadings (Such as calcium carbonate, titanium di-oxide, china clay, barium sulphate, aluminium hydrate, zinc oxide etc.) which may behave differently in different temperature and moisture conditions. Whereas for paper sample 2, in between -60°C to -30°C, coefficient of linear expansion has been increased and after 8°C it is decreased . This may be due to the presence of cellulosic fiber in combination with different internal sizing agents and surface coating agents added to the paper at the time of paper manufacturing in different proportions that behave differently in different temperature.

Figure 7 and 8 shows the change in specific heat with temperature for both blanket and paper consecutively. In case of blanket it decreases up to 70°C and attains a constant value till 850C and thereafter it slightly increases. This may be due to multilayer composition of the blanket containing woven fabrics, followed by polymeric layer. At the temperature of 700C and above, these composite attains optimum specific heat. But after 85oC, it shows slight increasing behaviour. This may be due to glass transition temperature of the vulcanised rubber material of the blanket.

For paper sample 1, specific heat decreases and attains a constant value till 940C then it increases slightly till 980C and thereafter it decreases.. But in case of paper sample 2 decrease of specific heat is gradual but attains a constant value earlier than the previous sample but again it shows increasing tendency after 780C. This may be due to the presence of cellulosic fiber in combination with the sizing agents such as Rosin, Alkenyl succinic anhydride (ASA), Alkyl ketene dimer (AKD)

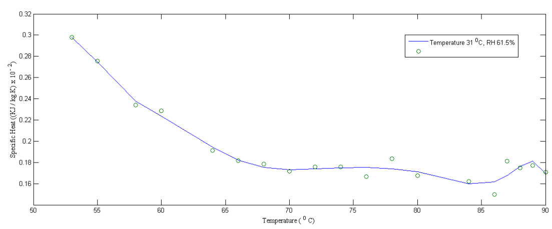

Figure 7 *Variation of specific heat of blanket with temperature.*

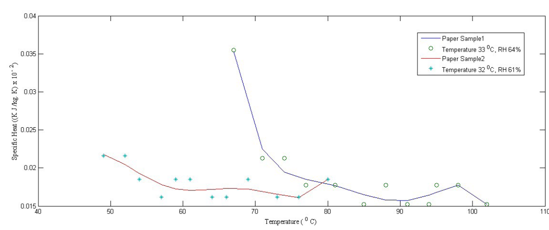

Figure 8 *Variation of specific heat of paper with temperature at different atmospheric conditions.*

in various proportions in different paper samples as they behave differently in different atmospheric conditions.

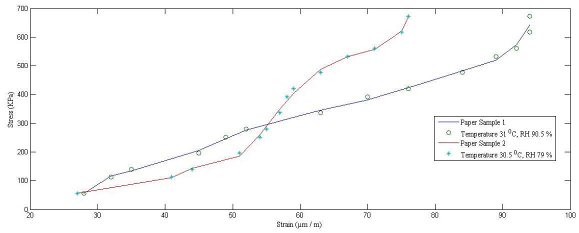

Figure 9 *stress-strain curve paper at different atmospheric conditions.*

Figure 9 shows the stress-strain plot of paper samples at different atmospheric conditions. The plots are obtained by regression analysis using MATLAB version 7.5.0. It is observed that temperature and relative humidity of the atmosphere had a great influence on the modulus of elasticity of paper. The paper samples show increase in strain with increasing stress.

The result of poisson's ratio also reflects the same result as paper sample1 has greater value i.e sample1 has better level of dimensional stability under longitudinal load than sample 2. This is due to the difference in composition of layers in the different sample of paper as different paper samples have different proportions of fillers, loading, sizing agents, polymeric cellulosic fiber and they are also beated differently during paper manufacturing.

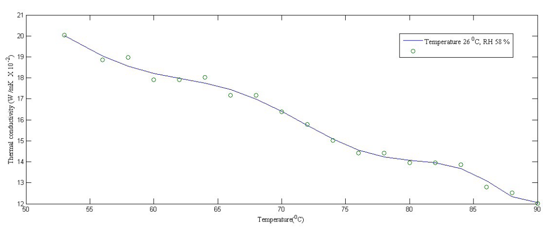

Figure 10 *Variation of thermal conductivity of blanket with temperature.*

Figure 10 shows that thermal conductivity of the blanket. It has been found that the thermal conductivity of the blanket decreases with increase in temperature. This is due to the multilayer composition of the blanket with different materials as it is a composite of 4 layers.

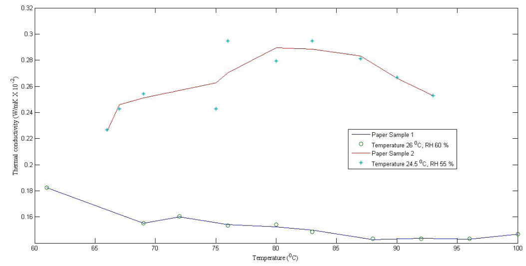

Figure 11 *Variation of thermal conductivity of paper with temperature at different atmospheric conditions.*

Figure 11 shows that thermal conductivity of the paper samples. For paper sample2 in the temperature range of 65-830C thermal conductivity increases with temperature and thereafter a deceasing nature has been seen. This may be due to the presence of polymeric cellulosic fiber, fillers, loading and sizing agents which behave differently in different temperature. Whereas, for paper sample 1 thermal conductivity decreases with increasing temperature. The relative humidity of the atmosphere as well as temperature influences the thermal conductivity. The heat conduction rate decreases with increase in temperature for paper sample1. But for paper sample 2 the heat conduction rate increases up to 830C and decreases with increase in temperature thereafter.

In high speed offset press, frictional heat [4] generated between the nip area of cylinders. A part of the heat is absorbed by the blanket surface according to the specific heat and the conductivity of the blanket depending upon speed, frictional coefficient of the materials and nip pressure [4,6,7]. Another part of the heat will be transferred to the paper, which will be either conducted to the next cylinder surface or will be absorbed by it leading to its dimensional change. The blanket carries the inked image from plate cylinder to paper and the part of the heat absorbed by the blanket will reduce the viscosity of the ink exponentially (as the inks used are of thixotropic in nature) leading to increase in dot size and thickness of lines. This will be cumulative due to the expansion of the paper as well as reduction of

the viscosity of the ink at the nip. However, as printing process is a combination of multiple parameters, particularly in offset, so, the effect of change in individual parameter is difficult to visualize.
For paper sample 1, specific heat decreases and attains a constant value till 940C then it increases slightly till 980C and thereafter it decreases.. But in case of paper sample 2 decrease of specific heat is gradual but attains a constant value earlier than the previous sample but again it shows increasing tendency after 780C. This may be due to the presence of cellulosic fiber in combination with the sizing agents such as Rosin, Alkenyl succinic anhydride (ASA), Alkyl ketene dimer (AKD) in various proportions in different paper samples as they behave differently in different atmospheric conditions.

5. Conclusion

One of the purposes of the water in dampening system of the offset printing is to cool down the temperature of the plate-blanket but still temperature in the nip of Web Offset Press (while running) is quite high [13] and the temperature of the blanket is more than 32oC after stopping of the press [14].
The paper has the tendency to change in dimension due to rise in temperature as found in the results. The specific heat and thermal conductivity of both paper and blanket are very low.
The heat will be transferred from blanket to paper at the time of image transfer in the nip of Plate and Blanket Cylinders. This causes expansion in the paper.
The paper is made up of fibrous materials (cellulose & hemicelluloses) along with different fillers, loadings and sizing compounds to get surface finish and optical properties. The paper will be expanded in contact with moisture as paper is made up of cellulose and hemicellulose which are in fibril form and increase in diameter due to moisture absorbance. If the paper is expanded due to heat, the expansion will be cumulative and will affect the registration of colour as image is printed by superimposing four colours - cyan, magenta, yellow and black.
In case of web offset, the paper passes under high tensile strength. The Paper will expand in the grain direction and will be shortened in the cross direction.
This has been confirmed by the measurement of Poisson's ratio of the paper samples. Though the tension is limited to the elastic limit but still it may affect the print quality creating permanent deformation if the applied tensile load is beyond or near to the elastic limit of the paper.

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