Infrared thermography examination of paper structure

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ABSTRACT

Recently developed laboratory tests for paper structure use an infrared camera for passive measuring methods. The technique adds mechanical or thermal energy to a sample to effect a temperature change. The new test methods help to characterize the structure and functional properties of paper.

Application:

Measurements with an infrared camera can provide information about the structure of paper.

THE PAPER INDUSTRY HAS USED infrared cameras primarily for troubleshooting. Examples are the examination of the condition of dryer fabrics and dryer cylinders and the analysis of moisture variations in a paper web. Another application extensively using infrared thermography is nondestructive testing of composite materials. This paper presents some recently developed laboratory methods using an infrared camera to examine paper structure. Specific areas include cockling, moisture content, thermal uniformity, mechanism of failure, and an analysis of the copying process.

MEASUREMENT OF COCKLING

Cockling in paper adversely affects its end use. Cockles in copying paper may cause the so-called deletion problem. This refers to the complete surface of paper not touching the copier drum, providing uneven transfer of toner to the paper.

Measurement of cockling is laborious, and no suitable standard exists for its definition. Bin capacity is one way to measure cockling. This is a number indicating how many sheets of paper of certain weight the standard pocket of a copying machine can hold. A more exact analysis would require measuring the entire surface and analyzing that data. Some laboratories have adopted a scanner to measure distance and provide topography analysis. A disadvantage of this apparatus is the slowness of the scanning procedure for large surfaces.

In our method shown in **Fig. 1**, we place a paper sample on a plate whose temperature is constant and higher than that of the surroundings. Changing the moisture content of the sample by moisturizing, drying, or copying before analysis provides a visible effect of the tendency of the paper to cockle. Depending on the objective of the examination, one can analyze the cockling immediately after the preliminary treatment or after ventilation of the sample before analysis.

Because of heat transfer between the plate and the paper, the paper temperature stabilizes at a level that depends on the distance between the paper and the plate. A camera operating in the infrared range then measures the paper surface temperature *(1)*. This provides a measure of the entire surface at once for placement in a picture file for later analysis. **Figures 2 and 3** show pictures of typical newsprint and fine paper samples.

Measuring both sides of the sample reduces the effect of curving. The size of the area analyzed is typically 150 mm by 150 mm. The analysis yields several characteristic figures—machine direction (MD) and cross direction (CD) variations, residual variation, and the size, form, and sharpness of the cockles. Residual variation correlates well with the bin-capacity measurement used in paper mills *(2)*.

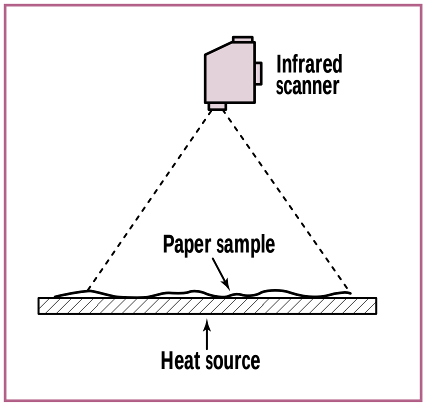
The infrared camera method compares somewhat with the scanner method measuring distance. There was a correlation factor of 0.82 for residual variations in a set of 30 samples. In addition, the tests revealed that analyzing ten samples at each test point gave good measurements of cockling. Sometimes even five analyzed samples sufficed. The method is suitable for quantitative measurement of cockling, based on testing with several paper grades.

MEASUREMENT OF MOISTURE FORMATION

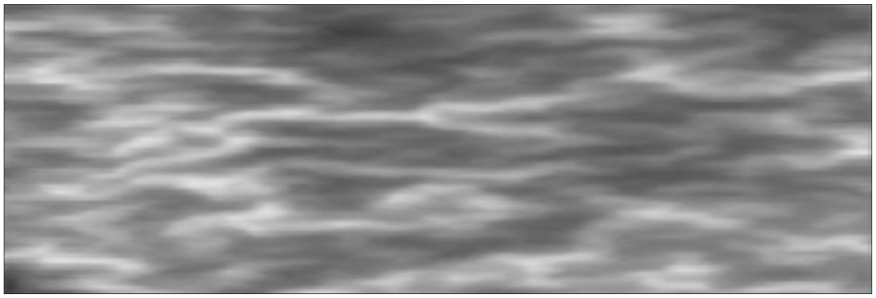
During heating, different areas of paper shrink from drying at different rates because of irregular structure. This causes wrinkling, cockling, and curling. Infrared techniques often measure the moisture content of paper. In such cases, the diameter of the measured area is approximately 20 millimeters. Small moisture fluctuations are not easy to measure using the commercially available techniques.

With our suggested method, we examine the inhomogeneity of paper structure using an infrared camera and a suction box covered by a fabric. The moisture content of the paper is initially approximately 40–50% (press dry). If the paper sample is dry, we moisturize it between sheets of moist paper. At a sufficient moisture level, we place the paper sample on a suction box whose vacuum is at a desired level.

Because of the inhomogeneous structure of paper, the drying rates at different points of the sample are dif-

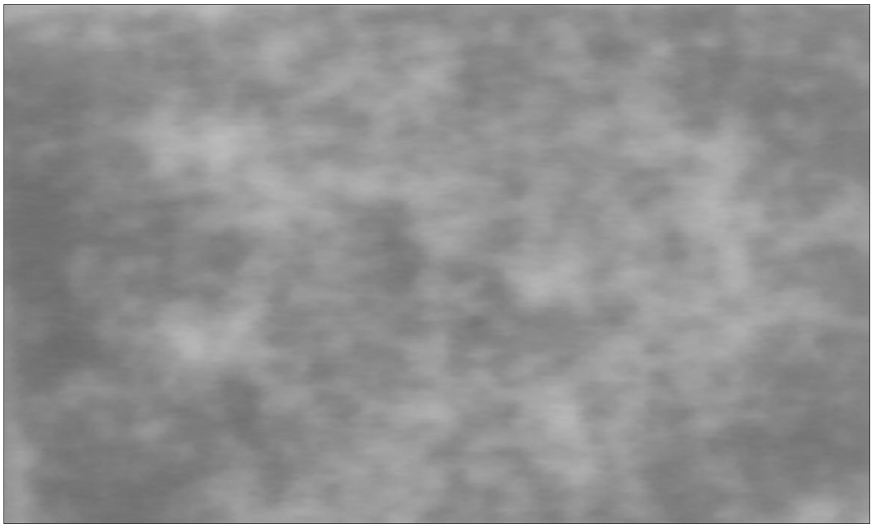


1. Schematic of method showing sample placement



2. Cockling in a newsprint sample

3. Cockling in a fine paper sample



4. Lightweight coated paper sample during suction drying

ferent. The structural irregularities in the paper such as fiber flocculation, uneven porosity, uneven distribution of filler materials and fines, etc., result in irregular local drying. Owing to these irregularities, the moisture content of the paper may vary locally, as **Figs. 4 and 5** show for two different papers. Local differences may also exist in the ratio between free and bound water.

During drying, the local temperatures of the paper reach equilibrium temperatures that depend on the corresponding local moisture contents. An infrared camera can observe the development of the differences in moisture content as the drying progresses. The differences in moisture content become clearly visible when the dry solids content exceeds 70%. They remain visible until the paper is almost dry. Depending on the vacuum level, the ambient temperature, and humidity, the drying takes only a few minutes.

The image analysis from the infrared camera yields several indicators describing the regularity of the drying. These include the MD and CD variations, residual variation, the sizes of the wet and dry areas, ratios, intensities, and the magnitudes of the differences of moisture contents.

MEASUREMENT OF THERMAL NONUNIFORMITY

The thermal properties of paper—heat conductivity, specific heat, and local density—are significant factors in drying and electronic printing. Evaporation of water takes the most energy in drying. The specific heat of water is approximately three times that of dry paper. Determining the specific heat of paper therefore does not improve the accuracy of drying models.

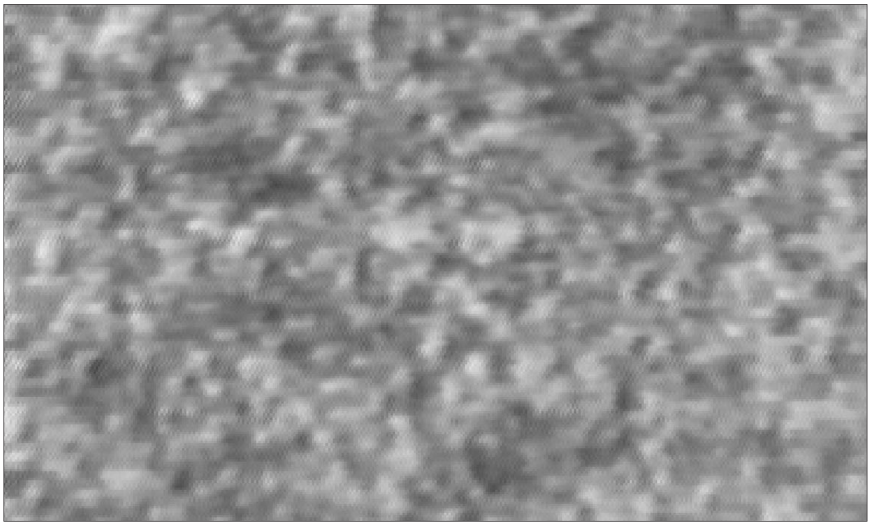
Heat conductivity is the primary factor when simulating drying. Since paper is a porous and hygroscopic material, heat conductivity depends heavily on local density and moisture content. There are several methods to measure the heat conductivity of paper *(3)*. A common feature of the various methods is that the result is only an average over the analyzed area. It does not account for any local variation in heat conductivity.

In nondestructive testing of composite materials, one supplies a certain amount of heat to the sample through the front or rear and observes the sample surface temperature using an infrared camera. If the different materials of a composite structure separate because of a manufacturing defect or the like, the heat conductivity of the sample is different. This defect usually shows as a warmer spot in the picture seen by the infrared camera *(4)*. Analyzing the defective area observed for dynamic thermal behavior can provide an estimate of the size and depth of the defect. If the heat pulse and the infrared camera are on the same side of the sample, one can divide the measured data into strata across the thickness to obtain dynamic thermal tomography *(5)*.

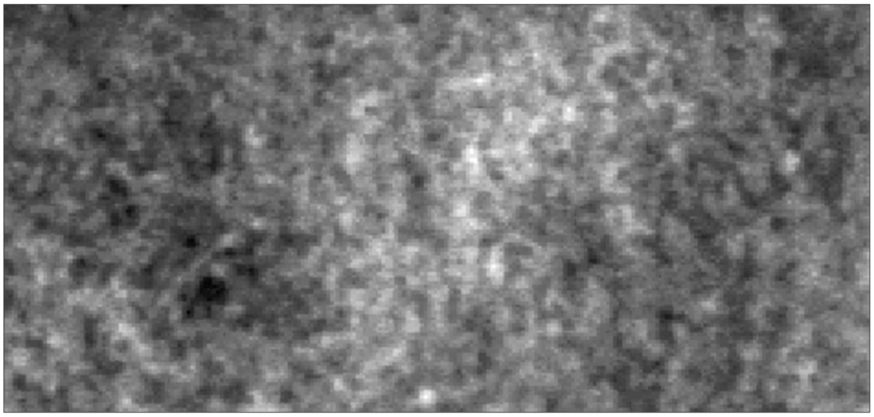
The method described above is a satisfactory technique for analyzing paper. Because of the thin samples, the test arrangements are more demanding than when analyzing thicker composites. Instead of finding defective areas, the examples of dynamic data shown in **Figs. 6 and 7** allow calculations of variation in local heat diffusivity. When analyzing the same paper at different levels of moisture content, one could also obtain information on the bond between water and paper in the *x–y* plane.

Other investigators have studied the anisotropy of composite materials by heating locally with circular or square heaters *(6)*. A corresponding technique could also apply for the analysis of heat conductivity of paper.

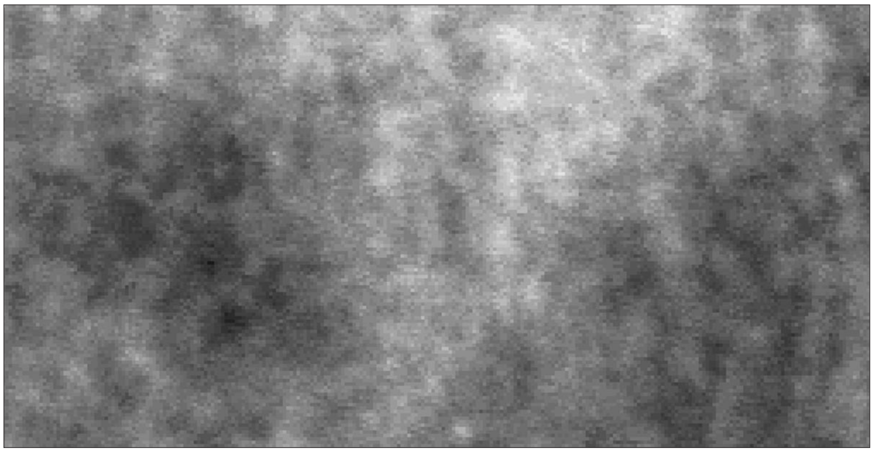
When heating paper with a circular heater and analyzing the paper temperature distribution at equilibrium, one can approximate the distribution as elliptical. By calculation, one can then obtain a characteristic figure describing anisotropy. Varying the size of the area heated and using several tests on the same paper will give an estimate of the heat conductivity variation over the plane.



5. Fine paper sample during suction drying



6. Thermal image of a fine paper sample immediately after a 1/750-s heating period



7. Thermal image of a sample 0.5 s after heating

OBSERVING THE PAPER FAILURE MECHANISM

A tensile strength test pulls a paper sample typically 15 mm wide at constant velocity. The test records the strain and the force applied. The tensile stress causes local deformations in the sample. These appear in infrared pictures as different temperatures at the different locations *(7)*.

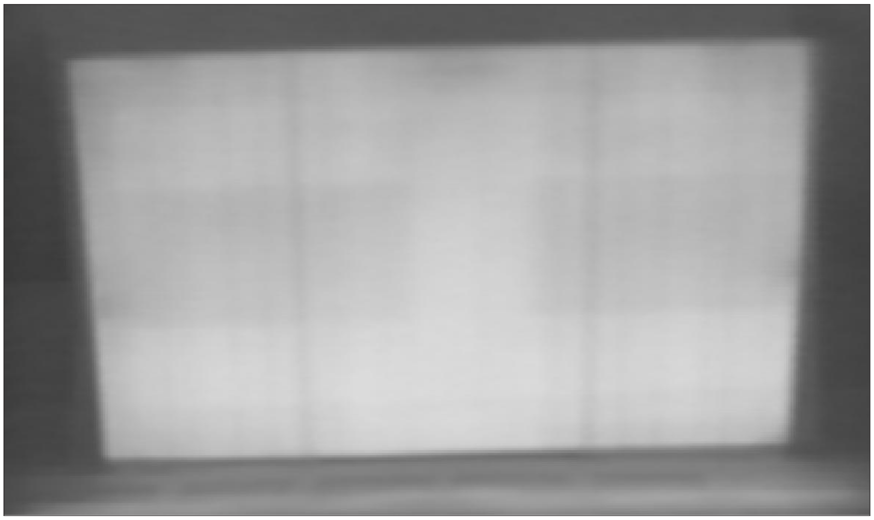
During plastic deformation, the

deformations are homogeneous over the entire area of the sample. In approximately the middle of the plastic range, higher local stress concentrations occur in the paper, giving higher temperatures. Failures begin at these locations *(7)*.

ANALYSIS OF THE COPYING PROCESS

In a copying machine, paper undergoes mechanical and thermal stresses. Water evaporates from the paper during heating. Because the application of heat is only through one side of the paper, the paper often curves or curls. Using values of paper temperature and moisture content obtained by measurement at a location after the heated nip, investigators have constructed a drying model *(8)*. Use of this model can analyze the curl of paper in the copying process.

Heat conduction into paper may be unequal at different locations across the paper width. This may cause irregularities in the gloss of the copy print. There is a distinct correlation between paper temperature measured with infrared photography and the quality of the copy *(9)*. **Figure 8** shows an example of a print.



8. A4 sheet immediately after the color copying process

CONCLUSION

The infrared camera is a versatile measuring instrument to examine paper structure. Although the temperature itself may not be the actual focus of interest, it often correlates in paper technology with a more interesting property. Such correlations are advantageous in the methods of analysis described above.

Our methods are still in the development phase, and no equipment is commercially available now. The methods described can yield information on the distribution of water absorption and liberation in the direction of the plane. Besides research on drying, this information may be useful in studies aimed at improving the uniformity of various kinds of print. **TJ**

KEYWORDS

Cameras, infrared radiation, measurement, measuring instruments, paper properties, paper structure, test methods, thermography.

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