TECHNICAL NOTE

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Photoelastic Stress Analysis of Film Ribbons

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ABSTRACT: Diffused polarized-light microscopy reveals detailed patterns in the film base of used typewriter ribbons inside the de-inked letter impressions. The multicolored patterns, which are observed to match the complex paper fiber configurations found at corresponding letter sites on the typed page, are theorized to be a manifestation of photoelasticity. Wavelength-dependent phase retardation differences, as a result of strain birefringence, correspond to retained microscopic deformations produced in the ribbon base polymer by paper fibers at the page surface at the instant of typing impact stress. Diffuse illumination is observed to enhance such embedded patterns relative to interfering surface features such as manufacturing striations.

KEYWORDS: questioned documents, typewriters, microscopy, typewriter ribbons, impressions

A complete discussion of polarized light [*1–3*], birefringence [*3*], phase retardance [*3*], strain birefringence [*3,4*], photoelasticity [*4*], and photoelastic stress analysis or PSA [*3–5*], is beyond the scope of this paper. Briefly, PSA is a method of using polarized light to render strain patterns visible, which is a useful engineering feat. The simplest PSA technique involves making a transparent plastic or glass model of the object to be analyzed, then observing the model situated between crossed polarizers by transmitted light as stress is applied to the model. A pattern of colors appears, which can be interpreted as a retardance map of stress-induced birefringence within the model resulting from molecular realignments.

The techniques described below, which use simple light microscopy, have been found by the author to improve resolution of typewriter ribbon impressions in two respects: exact type element conformance and delineation of paper fiber patterns from the typed page that have been retained in the polymeric ribbon base. The fact that these traces exist has been in the literature for more than a decade [*6*]. Improvements are desirable because discovery of the questioned text on a suspect machine's ribbon does not necessarily indicate direct association. Experience has shown that multiple typings of the text in question may appear on a suspect ribbon, in addition to any requested exemplar passages of the questioned text which investigators may have added.

During microscopic examination of a used single-strike film typewriter ribbon, the author placed a matte finish (nonglare) Polaroid™ plane polarizer beneath the specimen

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and made observations through a clear rotatable analyzer plane polarizer in the crossed, or extinction, orientation. Complex, multicolored patterns appeared in the letter-shaped pigmentation voids in the ribbon. The patterns were strongly suggestive of the microscopic appearance of tangles of paper fibers which are well known, by daily acquaintance, to forensic document examiners.

Subsequent observations, using known, carefully shepherded typewriting standards (ribbon segments and page positions of each character) verified correspondence of the colored patterns to the specific paper fiber patterns at the sites of the typed letters. Conventional reflected-light microscopy was used for examining the paper fibers on the typed page.

During the observations, various illumination schemes were evaluated in an effort to enhance the desired paper fiber patterns while minimizing unwanted interferences from other types of minutiae such as dust motes and longitudinal manufacturing striations. Kohler illumination and other collimated illumination conventions [7] normally favored were found less effective in this application because of their tendency to emphasize such surface features; also, an undesirable metallic, opaque appearance was imparted to the ribbon's image. (For collimated-light illumination, the lower polarizer must be optically clear.) The use of soft, diffuse illumination was found to be the most satisfactory. One caution, however: do not position any diffusing material *above* the lower polarizer, as it will promptly unpolarize the illumination.

The colored patterns observed between crossed polarizers are somewhat smaller than the overall letter-shaped ink voids observed without polarizers. The colored central areas, lying just inside uniformly colored or clear border areas (which in turn border on the inked unused background) were found to correspond very closely with the exact typefont element in use, including small defects. The larger de-inked areas, while still recognizable as letters, are much less detailed and less matchable to a specific font element. The borders are thought to result from pigment layer breakage and from ink transferred to the page in a wiping motion by the non-foot surfaces of the typing element. The increase in specificity afforded by the crossed polarizers is striking and can be compared with the conventional appearance by rotating the analyzer polarizer into, then out of, extinction position. The border areas of each impression, which surround the central photoelastically stressed areas, may appear clear, dark, or uniformly colored depending on such factors as phase retardance of the unstressed film base, depth and angle of the impression sidewalls, and orientation of the specimen with respect to the polarization directions of the crossed polarizers.

The photoelastic stress patterns persist even when the surrounding ink layer is completely removed from the specimen by organic solvent washing, which renders the ribbon transparent and completely featureless to casual observation.

Procedure Using Plane Polarizers

Refer to Fig. 1. The two polarizers should be crossed, that is, have their polarization axes at 90° to each other, so that no light is passed by the combination in the absence of a specimen between them. When a specimen ribbon is introduced between the polarizers, the stressed, birefringent pattern "lights up" in pure, brilliant colors against the overall dark field of view. The colors, but not the fiber pattern, vary, exchanging locations with each other and with dark fringes as the specimen is rotated. The physical explanation is that the extinction of the crossed polarizers is being defeated by phase retarding areas of the birefringent specimen. Although birefringence is an intensive property of the polymeric ribbon base, and resultant phase retardance varies with thickness, the relatively uniform, unpatterned retardance of the film has been altered along strains produced by the drop-forge-like process of typing impact with the page's paper fibers.

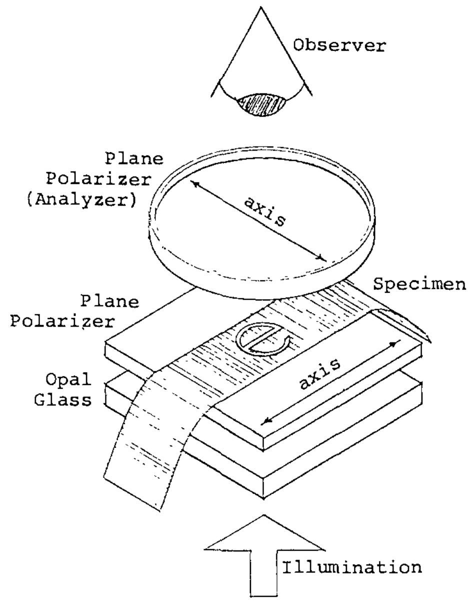

FIG. 1—*Procedure using plane polarizers.*

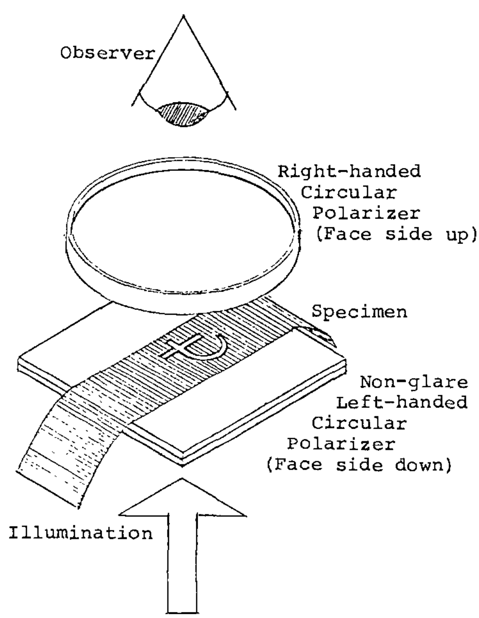

FIG. 2—*Procedure using circular polarizers of opposite handedness.*

Procedure Using Circular Polarizers of Opposite Handedness

Refer to Fig. 2. This use of circular polarizers is far removed from their more common function of glare reduction. Most circular polarizers are designed to polarize light that passes through their face side circularly, then block mirror reflections (which reverse the handedness of the circularly polarized light) from passing back through from the reverse side.

A combination of two parallel circular polarizers of opposite handedness, that is, one left- and one right-handed, pass no light in any rotational configuration as long as their retarder layers face toward the inside of the combination (face sides out). The visual effect on a film specimen observed between two such circular polarizers is that specimen areas of equal retardance appear the same color regardless of specimen orientation. The difference between this appearance and that resulting from crossed plane polarizers would probably not be worth the considerable trouble which may be encountered in obtaining circular polarizers of opposite handedness, although some convenience may result from the fact that the circular polarization scheme does not necessitate rotation of the analyzer (upper polarizer) to any specific position. Circular polarizers of the HNCP type consist of a layer of plane-polarizing material bonded, at a rotational angle of plus or minus 45°, to a layer of a material which exhibits 90° phase retardance over a wide range of wavelengths. If a 90° (quarter-wave) optical grade retarder is available, circular polarizers of either handedness can be assembled using plane polarizers. The author notes that a Niko™ brand circular polarizer camera filter in his possession is of opposite handedness to the normal (left-handed) HNCP-37 circular polarizing material available from the Polaroid Corporation.

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