Army Research Laboratory

Dichotomous Results Using Polarized Illumination With Single Chip Color Cameras

by Donovan Harris

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14. ABSTRACT
The report is not the result of a focused study but an accumulation of issues encountered during a variety of projects requiring the use of polarized light, addressing color-consistency problems experienced using commercial, single-sensor digital cameras with linearly polarized illuminants. Using an unfixed polarizing film sheet contrasts to using a commercial polarimeter. Experiences with on-camera processing, white balance, color space, file format, tethered operation, and the use of PC processing software are discussed.

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1. Introduction

This technical note addresses a series of issues experienced using digital single lens reflex (DSLR) cameras in nonquantitative polarized light studies. A color or white balance problem appeared to develop over a 6-year period, while other issues became apparent while trying to correct the initial color problem and with additional studies. The DSLRs either document macroscale samples, experimental setups, and generating qualitative images using polarized light. The color issue, correction efforts, and results only warrant a brief review, owing to the ever-changing nature of the DSLR technology and supporting software applications. The number of images is kept to a minimum as the accuracy of color reproduction can suffer in print. The conclusions take the form of practical suggestions for avoiding or being able to identify the problems discussed here, as the changing technologies may void any detailed correction procedure presented.

2. Background

Microscope or camera pairs with digital image correlation applications generally perform quantitative digital imagery of materials. The microscope is limited to bench-scale samples. Hand-held digital cameras are mostly for noncritical macroscale documentation of samples and experimental setups, qualitative data. When employing polarized illumination, an otherwise purely visual image can assume a quantitative nature that is not justified. Our six mega-pixel point-and-shoot camera works well for recording scenes where image resolution will never be an issue. DSLRs, 10.6–12.4 mega-pixels, are employed to document specimens to be sectioned and any items sent out for evaluation and analysis.

For 2000–2006, the protocol for performing polarized light imaging was specimen-size dependent. One- to 2-in-sized items were imaged using a polarized light microscope with a three-chip color camera. Two- to 4-in samples were examined using a polarimeter, a Wild M420 Makroskop, and another three-chip color camera. The polarimeter, on a reproduction stand, and a DSLR with a 20-mm lens examined samples up to 6 × 6 in. Larger samples required using linearly polarized films, a diffuse source for backlighting, and a DSLR.

The performance of older DSLRs, circa 2002, suddenly changed over 40 days, the probable result of sensor aging or direct exposure of the Bayer arrays to ultraviolet (UV) radiation, 295–365 nm, or a combination of both. The Joint Photographic Experts Group (JPEG) format images generated did not agree with the visual observations and were not readily correctable by a simple gamma or white point adjustment. In contrast, older three-chip color microscope cameras, circa 1997, performed well until computer hardware and software supportability no longer existed, necessitating the expanded use of the DSLRs.

Post-processing of the camera generated JPEG format files to correct the obvious visual/color errors and generated the question of where does a correction become a creation, necessitating a new DSLR to replace the two older units. Another new project, a dedicated DSLR, arrived at about the same time. These two cameras photographed the identical samples as the older units, using the same polarimeter for cross polarization. The resulting images moved closer to visual observations but did not replicate them. The two cameras were consistent in the images each produced and in the color differences between them. Again, a simple gamma adjustment to the JPEGs proved ineffectual, and the white point adjustments produced extremely distorted results.

2.1 Instrumentation and Software

The DSLRs included charged coupled device (CCD) and complementary metal oxide semiconductor sensor (CMOS) units. The camera lenses were either Nikon or Zeiss. The polarimeter was a StrainOptic, Inc., PS-100-SF.

The software programs for image processing were Adobe Bridge CS4, Adobe Photoshop extended CS3 and CS4, and Adobe Lightroom 2.3 and 2.4. Fuji Fine Pix Viewer, Nikon View NX, and Phase One Capture One DB4.8 provided metadata support for all camera images. Nikon Camera Control Pro 2 was the tether controller for compatible cameras. Initially, only the Photoshop Extended CS3 was available for use with the camera-processed images. Except for Photoshop and Camera Control Pro, all the applications possessed good but varying metadata reading capabilities.

3. Procedures and Results

A sample is either placed between two sheets of linearly polarized film illuminated using a diffuse backlight, figure 1, or on a polarimeter, figure 2, which incorporates a diffuse backlight. The camera generally requires a rigid support to minimize blur. The polarimeter works in conjunction with a reproduction stand, allowing the analyzer to be positioned against the camera lens once sample focus has been achieved and reducing back reflections. Using paired polarizing films in place of a polarizer tends to generate surface reflections from the surrounding environment. Sample and film positioning may reduce or eliminate those reflections.

The camera settings are adjusted so that the capture image and visual image appear as reasonable facsimiles of one another. The procedure and the images are specifically for documentation and not measurement or analysis. In specific instances, such as multiimpacted plates, the images must reproduce the observed strain field image as accurately as possible.

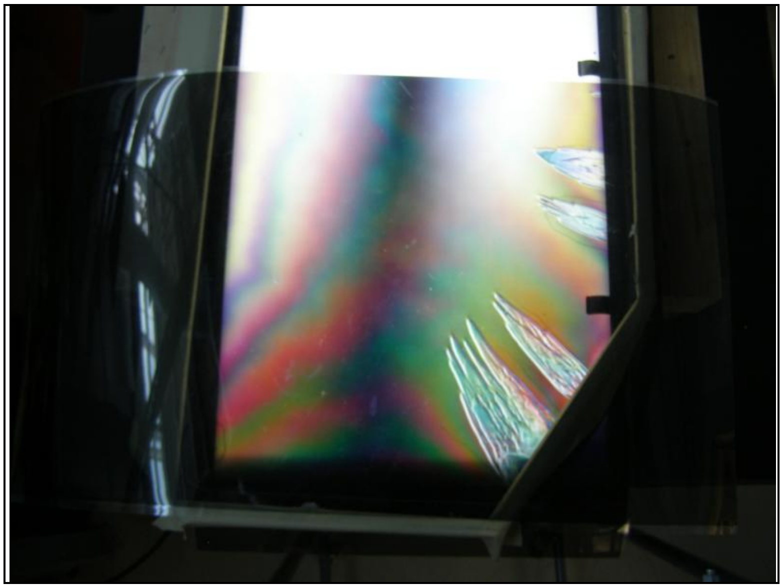

Figure 1. A typical polarized light setup using sheet material for visual assessment or a photographic record. The top section not covered by the analyzer sheet appears white because of the time of exposure.

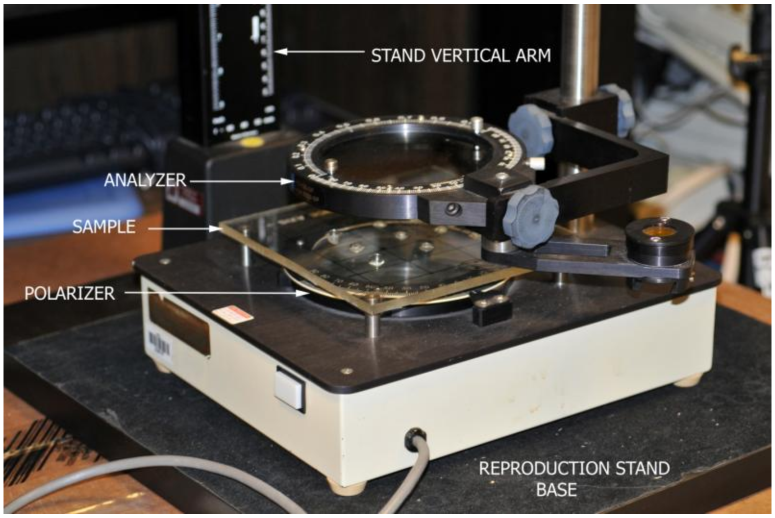

Figure 2. Standard polarizer use and sample size limitations.

The composite image in figure 3 illustrates a pre-shoot positioning on the left and the bowing of the polarizer and the analyzer sheets on the right. The tripod bar in the left image enables the camera sensor to approach a parallel plane with the sample surface, enhancing the capability to generate consistent images. Figure 4 readily documents the effect of shooting from random angles on the observed birefringence from one sample. The pattern in the lower frame originates in the bowed analyzer sheet.

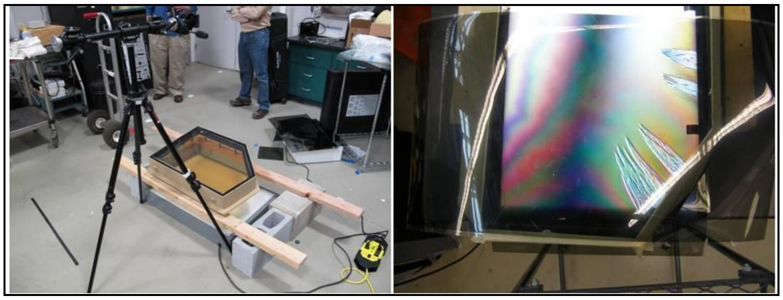

Figure 3. The two standard methods utilized to establish the camera sensor plane parallel to the sample face plane. The use of a tripod, left-hand image, or a mono stand is best. Space and sample size can preclude using the first two methods, leaving a safety ladder as the alternative, as shown on the right. Note the bow in the analyzer film.

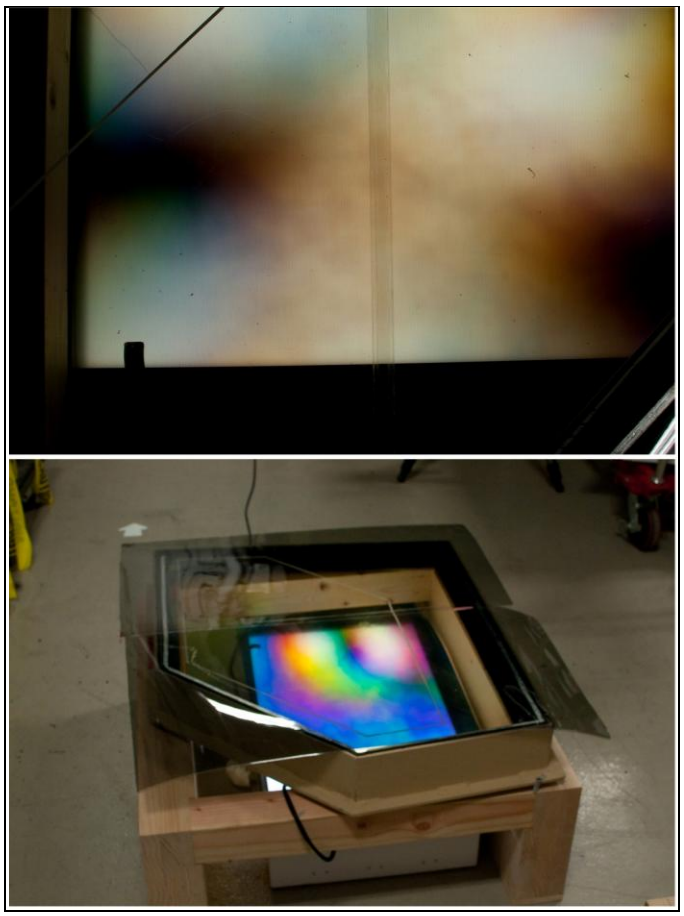

Figure 4. Effects of a bowed analyzer and an off-plane sensor on the observed birefringence.

Bowing of the film polarization sheets, while affecting the birefringence response, can be immaterial depending on the information actually required, as in figure 5. While the analyzer sheet bows toward the camera, the polarized light brings out details not otherwise visible.

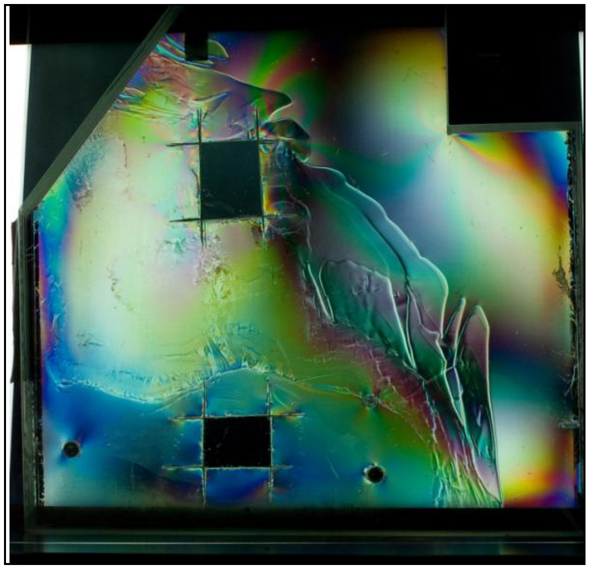

Figure 5. Birefringent response is both strain and chemically induced at an interior laminate layer interface. The size and location of the pattern are crucial and not the actual colors.

Potential color issues for presentation purposes may be eliminated by converting to gray scale, as done in figure 6. Generating gray scale images using a DSLR microprocessor can result in a loss of resolution, which could go unnoticed unless part of a large-scale presentation. Monitor display resolutions of the same images generally display below 50% in most viewers and under 25% in presentation slides until projected.

The birefringence generators in the previous figures are a single layer of a multilayered, multimaterial sample. Hence, laminates having multiple indices of refraction require a custom calibration for each of the architectures of interest in order to generate quantitative stress data.

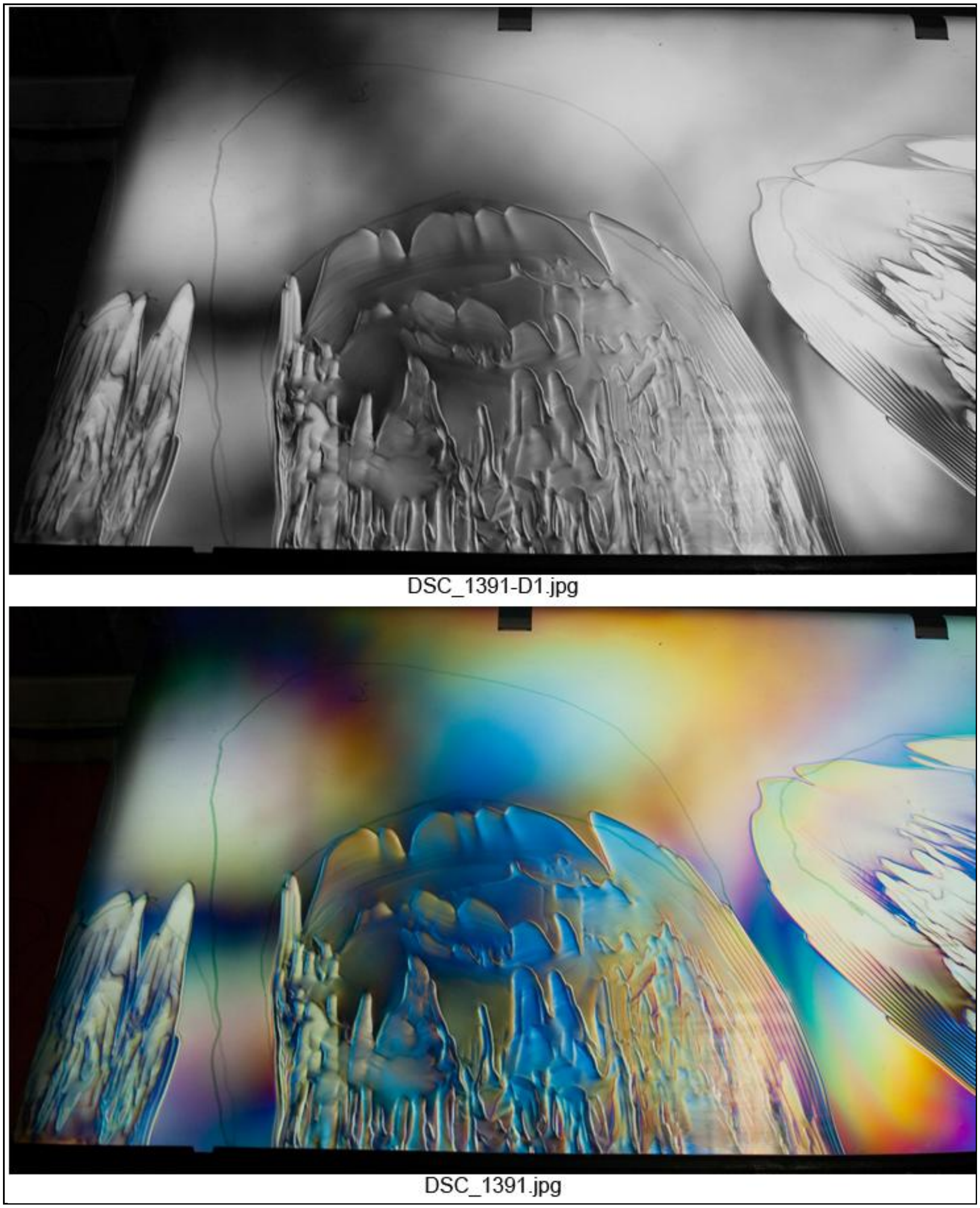

Figure 6. The use of gray scale to minimize side discussions concerning color.

Figure 7 represents a nearly ideal photoelastic test, a homogeneous material, a polarized light microscope, and a three-chip color camera to record the response. In contrast, figure 8 shows the two faces of a layer laminate in two orientations using a DSLR and free-standing film polarizers. All four frames show a blended birefringence from all the layers, complicating even a qualitative assessment.

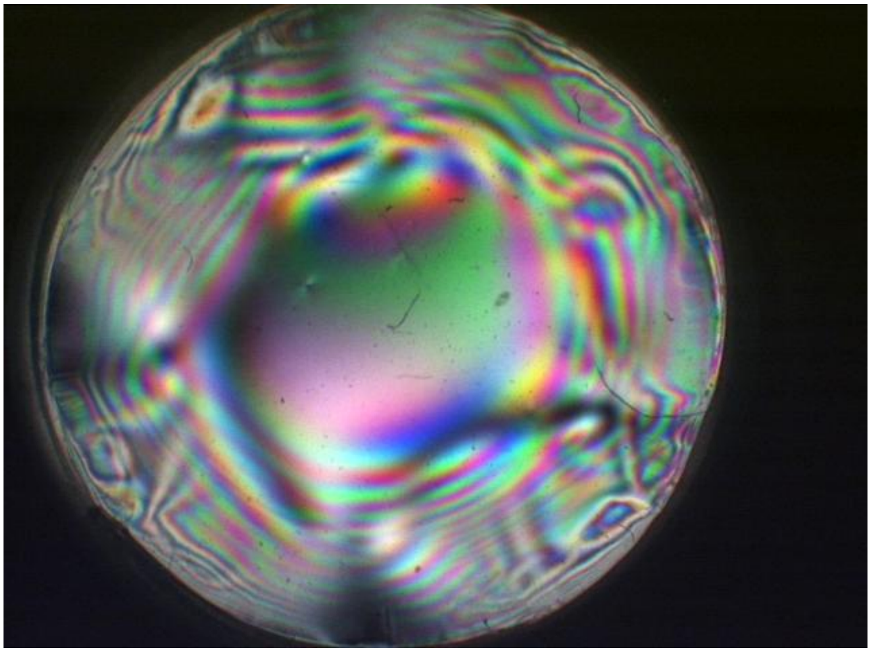

Figure 7. Captured photo using polarized microscope with a three-sensor color camera. The sample is homogenous, having a single index of refraction. This represents the ideal for making photoelastic stress measurements, which were not required for this sample.

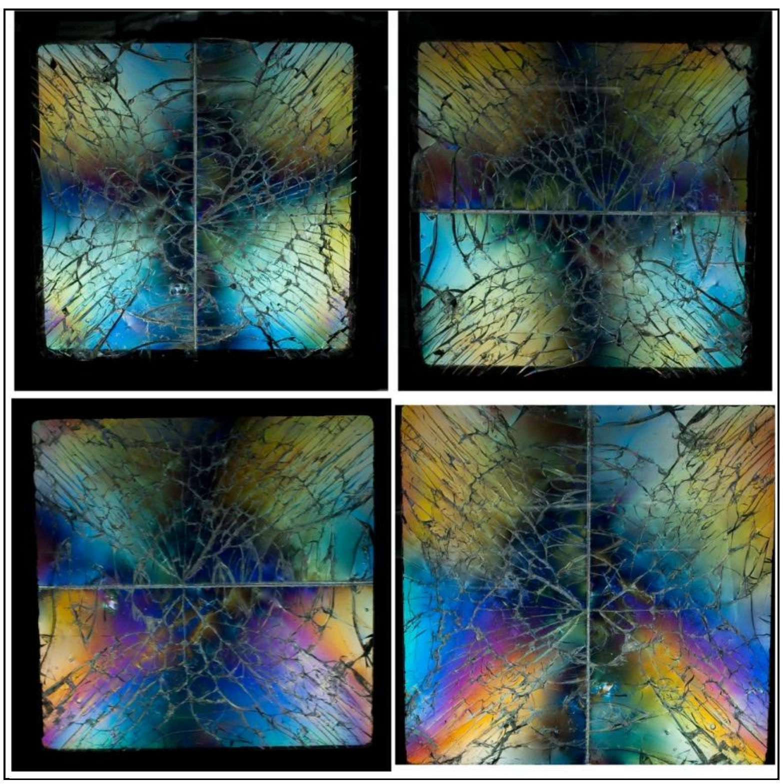

Figure 8. A single laminate as seen from both faces at two orientations. The observed responses are blends of two differing materials and residual stresses.

Figure 9 presents a similar scenario without any obvious blending interference, demonstrating that the observed birefringence originated in a single layer.

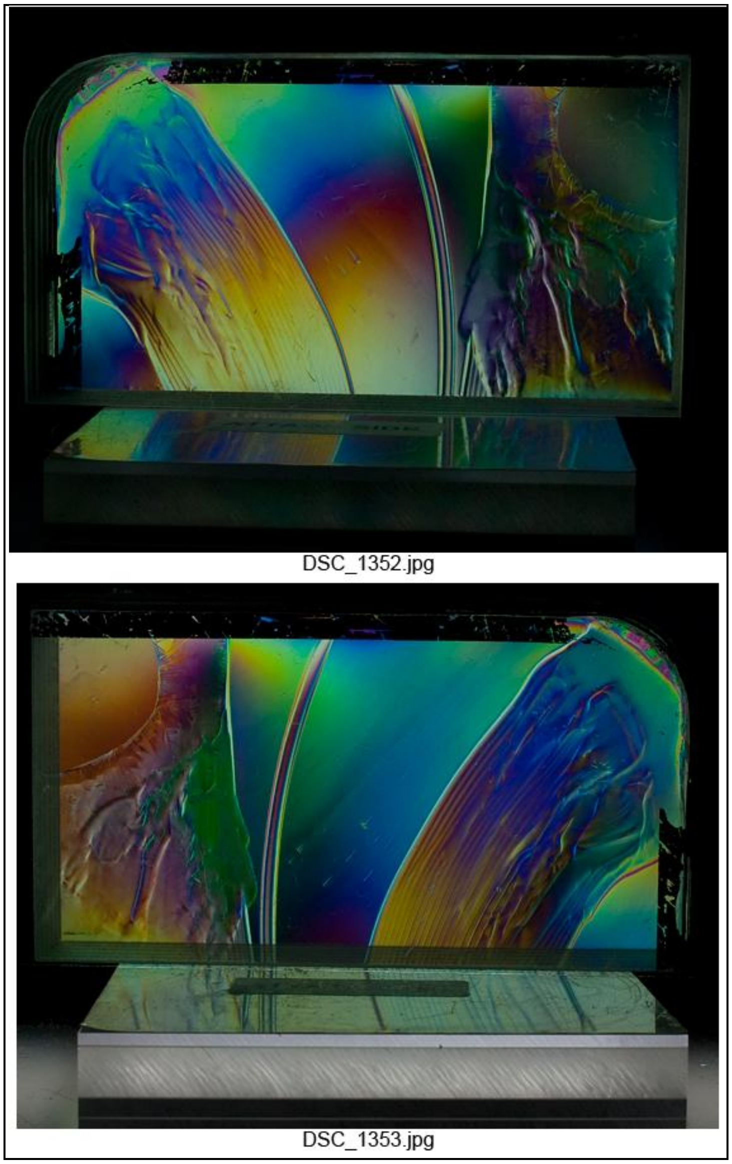

Figure 9. The observed response was isolated to a single layer of the laminate structure. The analyzer is in front of the base support in the top frame and on the sample support in the bottom frame.

The sheet polarizers-DSLR color issues discussed originated either from the setup or sample orientation. The color issues arising from using a DSLR with a polarimeter turned out more convoluted. The color differences between the images in figure 10 arose from a series of issues. The top frame used a cool white preset with an auto ISO setting generated by the associated application Apple software via a USB tether but was invisible to the on-camera display without accessing the proper submenu. The bottom frame was generated several months later using an auto white balance and a fixed 800 ISO setting. Both images utilized Photoshop processing, which could not display the full metadata. In the period between the two images, the UV/infrared filter in front of the camera sensor was removed to produce a better image using 265- and 365-nm light sources. The polarimeter appeared to be the source of the color change because the polarizer and analyzer films bubbled and wrinkled. One year later, a new Fuji DSLR designed for UV use brought the Windows-based software needed to access the full metadata.

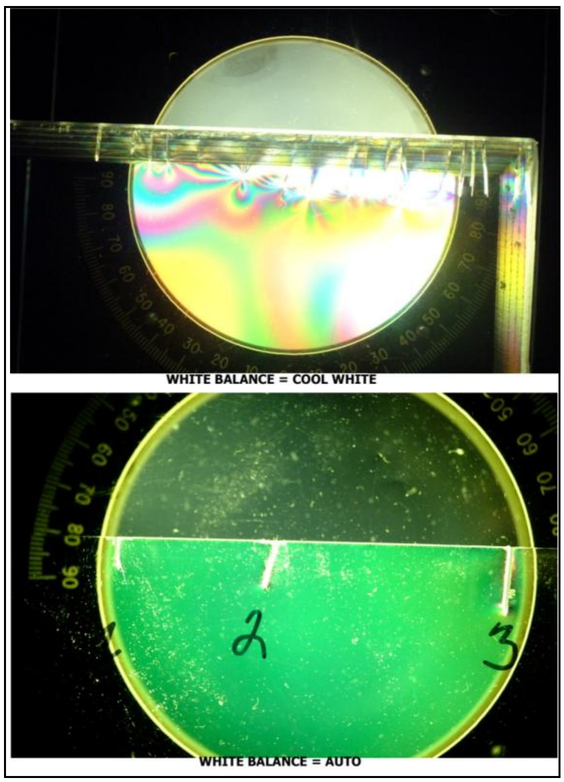

Figure 10. Images were both shot, with the top camera menu indicating an auto white balance setting, while the file's metadata indicated that two different white balances were used.

A standard configuration required for any shared resource was never established, while the Apple supported camera software limited it to a single computer. Those constraints inhibited a timely resolution of the polarimeter-DSLR color issue.

Post-polarimeter refurbishment, figure 11 is a composite image with the polarizer and analyzer fields parallel to each other and fully crossed, 90°. The left half of the image is the "zero" analyzer rotation portion. The UV filter information became known at this time, prompting the acquisition of the Nikon D300. The Nikon D80 later generated the comparison images for improved reliability. An ISO speed of 400, aperture priority at *f* 8.0, sRGB color space, and manual focus were standard starting with the Nikon DSLRs.

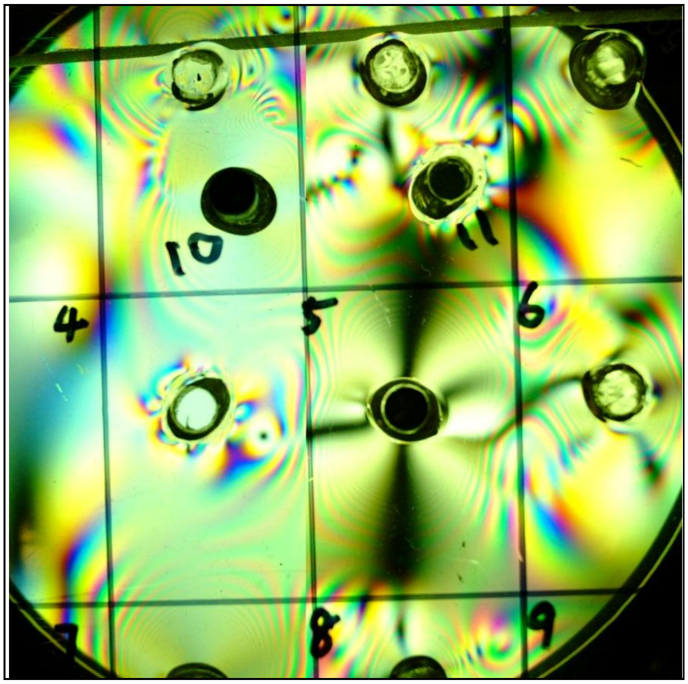

Figure 11. A composite image comparing parallel polarization response, left, and full-crossed polarization response, right. The two appear identical to the eye.

Creating a custom white balance or CP for D80 and D300 produced mixed results initially. The D300 had no problems with generating and applying a custom white balance, as demonstrated in figure 12.

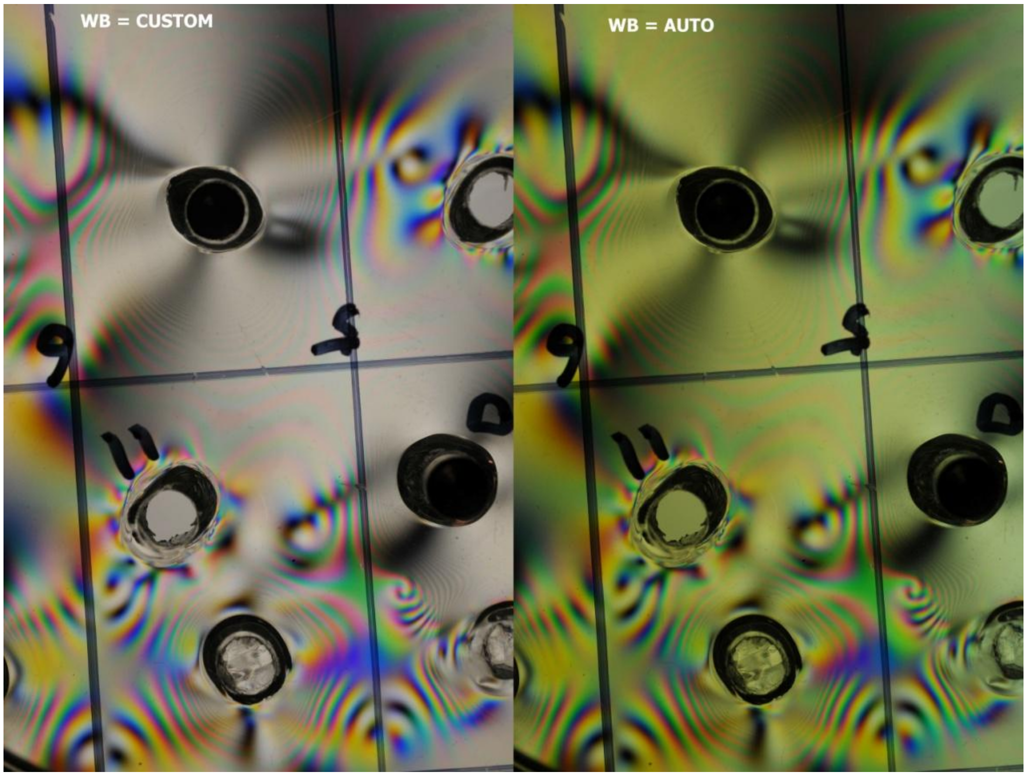

Figure 12. Photo contrasting the color response of the Nikon D300 employing a custom white balance, left, as against using the auto function, right.

Figure 13 contrasts the custom white balances generated by each camera following the manual instructions. Moving closer to eliminate any black and defocusing to blend, the darker and light patches worked. Operating in tethered mode proved the sole practical method in this instance. The D300 can store four menu-accessible custom points and the D80 can store one. The need for a CP for each lens, sometimes two for the macrolenses, rendered the regular use of CPs impractical. The cool white setting on the D300, while inaccurate, was the most color-consistent setting tested and made it the default for polarimeter work, figure 14. CP imaging is confined to reshoots of specific cool white images.

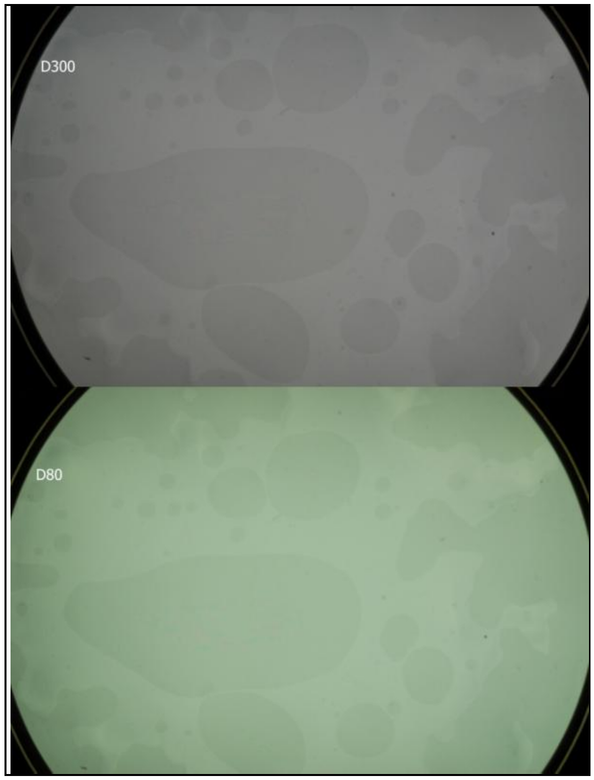

Figure 13. The results of generating custom white points following the manuals for the D300, top, and the D80, bottom.

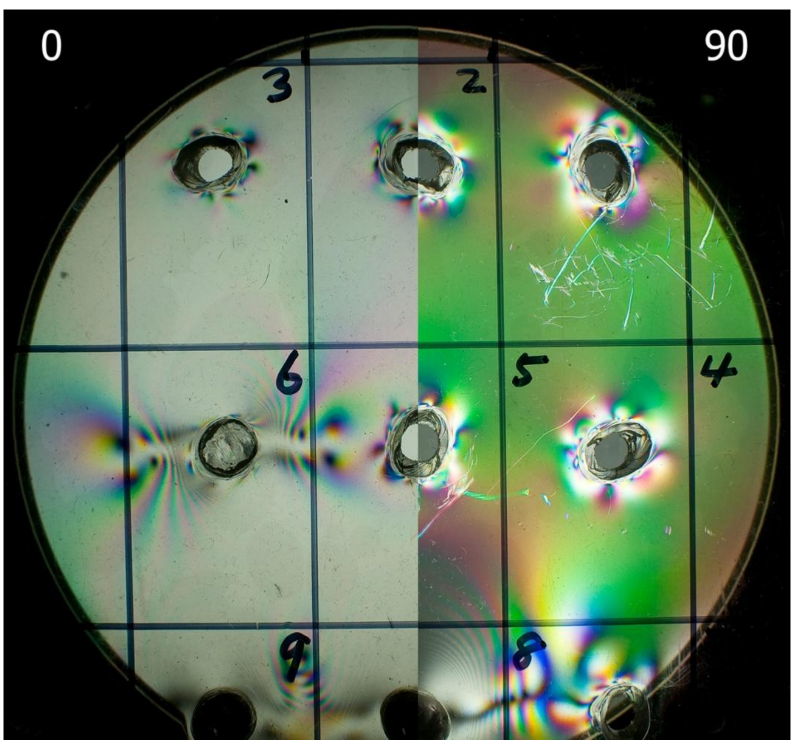

Figure 14. Another D300 composite showing the 0° and 90° results using a cool white setting and matrix metering on the D300.

4. Discussion

Being a single sensor system, a DSLR employs a mosaic array filter for color interpolation. Thus, the interfaces of the color bands tend to be distorted in either color or spatial placement. A CP cannot correct these distortions, which are not usually discernible in full-size images of 300 pixels/inch on a 1920 × 1200 pixel display.

Color space and file format influenced the appearance of the captured birefringence. Beginning with the Nikon DSLRs, nearly all polarimeter work used sRGB color with a raw file format. Cogeneration of a JPEG with the raw file proved counterproductive. Earlier, the S1 generated raw and tagged image file formats, and the 14N produced raw and JPEG formats; both used an Adobe RGB color space and had only Apple-based processing applications. The use of Adobe RGB on all DSLRs generated JPEGs and produced the widest color disparity, with the images resembling graphic illustrations.

The polarimeter designed for visual use and not digital imaging uses 1980s technology. Two F6 cool white fluorescent bulbs provided the illumination and were situated along each of the sides, with a wire-wound transformer for each. The present replacement lamps each listed a 295-lm output at 6 W. The failure of one lamp was not visually noticeable but very evident to the camera and undistinguishable from 60-Hz cycling, i.e., the light output varied directly with the 60-cycle voltage. The illumination varied with line voltage, impeding reproducibility throughout the day. The DSLR-polarimeter color issue was actually several interacting items all effectively masking each other's existence. A recently purchased copy stand with a light-emitting diode (LED) light box proved to be a very stable and consistent source of illumination when working with sheet polarizers. The unit was capable of variable levels of illumination, with a constant color temperature of nominally 5000 K. The available commercial LED polarimeters are limited to the food, beverage, and pharmaceutical industries. An advantage of a polarimeter over sheet polarizers is a scaled rotatable analyzer, which is required to investigate nonrotatable samples in a reproducible procedure.

Six megapixel point-and-shoot digital cameras are capable of color-accurate images but can be difficult to use because of autofocus, autoflash, and a limited ISO speed range. As with the DSLRs, the images tend to be underexposed. Unlike the underexposed DSLR images, the results can appear noisy/grain, lack definition, and not useable at full scale except for notebook documentation. The thumbnail images can appear to be "better" than a DSLR thumbnail of the same item. The luminous exitance/emmittance (lumens per square meter), emanating from the analyzer, along with the overall light level, appear to be determining with the point and shoots. Except for being able to set the ISO speed at 400 and sometimes disabling the flash, these cameras employed their auto functions.

The raw file processing software produced unexpected output changes with some updates. Version upgrade changes were expected but proved generally less dramatic than the version updates, except for the application graphical user interface interfaces. Raw data files should be backed up and stored separately from the working file storage prior to exposing the processing software. Copying the raw files after processing can lock in the process parameters to the raw baseline configuration, as the original baseline reference files may be stored in a different location.

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Kliger, D. S.; Lewis, J. W.; Randall, C. E. *Polarized Light in Optics and Spectroscopy*. Academic Press: San Diego, CA, 1990.

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