Determining the Drying Time of Printing Inks on Different Media by Laser Speckle Method

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Keywords: laser speckle, ink, drying, inkjet, lithographic, paper

Abstract

Conventional test methods for determining drying time of printing inks are subjective. The comment methods involve finger swiping and visual assessment or accompanied complicated procedures by rubbing tester with destruction of samples. These methods encounter difficulties in qualifying the extent of drying, thus, seem to be restricted to obtain comparative data of drying property. In this paper, the methodology of determining the drying time of inks on substrate by monitoring reflected speckle patterns arisen from ink surface by laser illumination was discussed. The dynamic alteration of speckle patterns corresponds to the fluctuation of microscopic structure of the ink surface with penetration and evaporation of dispersion elements. The methodology assumed when the correlation coefficient of successive speckle patterns captured by CMOS camera at a certain time interval is in a stationary state, the ink film is considered as dried. The method is objective, noncontact, and inexpensive. The experimental data of inks drying measured by the speckle method were compared with the result by ASTM F2498 for inkjet print and JIS K5701 for drawndown offset ink. The comparison results showed that the speckle method has good correlation for different media with ASTM F2498, however no significant relation with JIS K 5701 which leads to transference of the undried inner ink rather than surface. The reflective speckle is limited to observe the surface area of ink films. Transmitted speckle patterns of samples should be investigated to improve conformity test purpose as a future work.

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Introduction

There are several standardized test methods for determining the drying time of printing inks including inkjet inks and oxidative drying inks. These standards are based on human subjective determination such as tactile by fingers or accompanied complicated procedures with rubbing tester. These methods have difficulties in qualifying the extent of drying by a visual assessment and rubbing force. Thus, it seems to be restricted to obtain comparative data of drying property for combination of inks and substrates rather than a certain time of drying. The common methods usually destruct test samples. An objective, concise and inexpensive test method for determining drying time of ink film is desired as a valuable tool for evaluation and development of new printing inks.

In this paper, the methodology of determining drying time of printing inks on different media by monitoring reflected speckle patterns arisen from a ink film with laser illumination was discussed. A speckle pattern is contrasting random light pattern arising from laser illumination of diffusion surface such as paper, plastic or metal. It is emerged by random interference between corresponding light to microscopic bumpy surface and laser illumination. The asperity of surface needs to be sufficiently bigger than laser wavelength; the average clearance of salient on bumpy surface needs to be smaller enough than diameter of laser illumination spot (Yamaguchi, 2002). The dynamic alteration of microscopic surface structure could be monitored by capturing the temporal variability of speckle patterns.

Employing the speckle interferometry, the temporal change of liquid or gel materials could be detected. Some earlier studies showed how to monitor the hardening process of UV curable resign (Kobayashi et al., 2005) filled in cylindrical vessel and painting layer (Javier et al., 2001; Brunel et al., 2007; Yamaguchi et al., 2007) on substrate such as glass plate. Some other examples of noncontact measurements include using FT-IR, which employs monitoring functional group related to dry (Decker et al., 1990) and using terahertz paintmeter (Yasui et al., 2005) to detect the reflected terahertz electromagnetic waves from a sample. These methods accompany expensive apparatuses and are not suitable for simple and quick testing.

In our study, we focused on observating drying process of dribbled inkjet ink and drawndown offset inks on selected paper substrates. At the beginning, we examined appropriate speckle size captured by a CMOS camera at a constant time interval. The data size was then determined for computing correlation coefficient of successive frames of dynamic speckle patterns. Next, measurement and calculated results from dynamic speckle method were compared to test results obtained following ASTM F2498-05 (ASTM, 2005) and JIS K 5701-2000 (JIS, 2000) methods.

Experimental

Conventional Test Methods for Inks Drying

ASTM F2498-05 – Standard Practice for Determining the Drying Time of Inkjet Media and Inks Using a Smudge Method (American Society for Testing and Materials), defines a procedure for assessing the drying time of black and white or color images produced by inkjet printers by smudging color bars shown in **Figure 1**. As soon as the print is released from the printer, color stripes are swiped from the yellow bar to the black bar toward right direction using uniform pressure by finger with PVC glove. The actual time is recorded when smudging was no longer visible; a drying time is calculated based on the printing duration and time interval of smudging procedures. This method can be applied for various inks and substrates. However, the test result involves subjective determination of swipe operation and visual inspection.

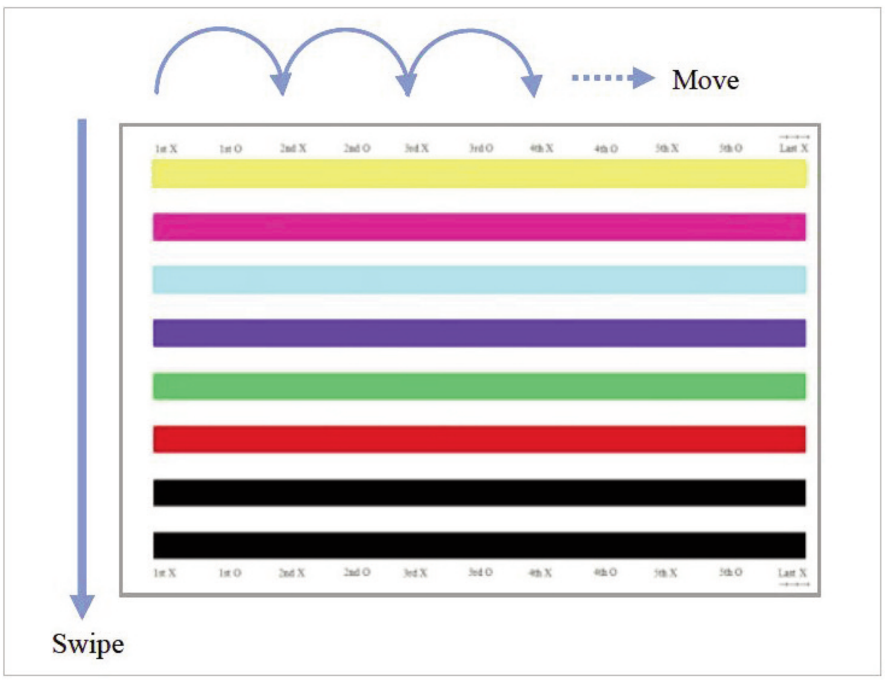


Figure 1: *Test form defined in ASTM F2498-05 standard testing method.*

Another standard method, JIS K 5701-2000 – Lithographic Inks – Part 1: Testing Methods (Japanese Industrial Standards), is based on qualifying transference of the undried lithographic ink film to a slip sheet when the ink film is pressured. It provides two kinds of procedure; using Ink Drying Tester Type-C and stamping rubber plug on ink films. Tester Type-C shown in **Figure 2** is generally composed with a rotating drum which is rolled up with drawndown ink paper and slip sheet, a tracking wheel with loading weight for turning over the test sample, and a moving rail which the tracking wheel could move along rotation axis of the drum. The distance between each tracking line by transference of undried ink on the slip sheet corresponds the period of 10 minutes. The method is fully automatic. However, it remains subjectivity about qualifying the tint tracking line on the slip sheet.

Dynamic Laser Speckle Method

The microscopic structure of an ink film surface fluctuates during drying accompany with penetration and evaporation of solvents as the result of rapid rising in viscosity of the ink film. Dynamic speckle patterns corresponding to the fluctuation are determined by correlation coefficient of successive frames of speckle image captured at a certain time interval to assess termination of speckles alteration. The diagram for the laser speckle device used for this study and specification of each component are shown in **Figure 3**. It is composed of inexpensive and commonly available parts such as diode laser (630 nm) and CMOS camera. Speckle patterns of the ink film surface arising from laser illumination set at 30 degree from vertical to avoid halation are captured by the camera set in a vertical direction. Electrostatic adsorption state or similar tool could be employed

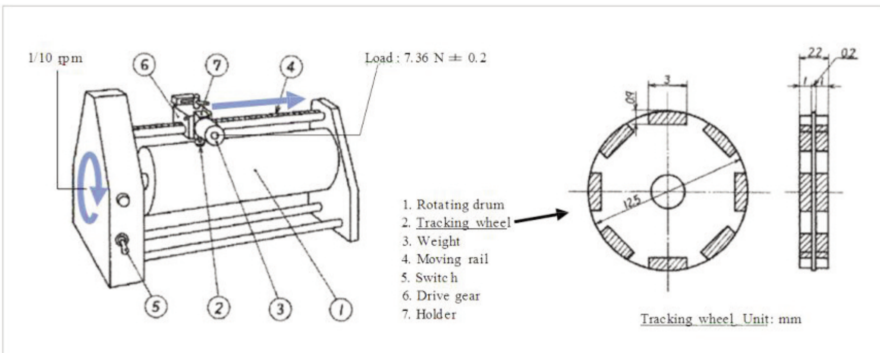


Figure 2: *The configuration of inks drying tester type C.*

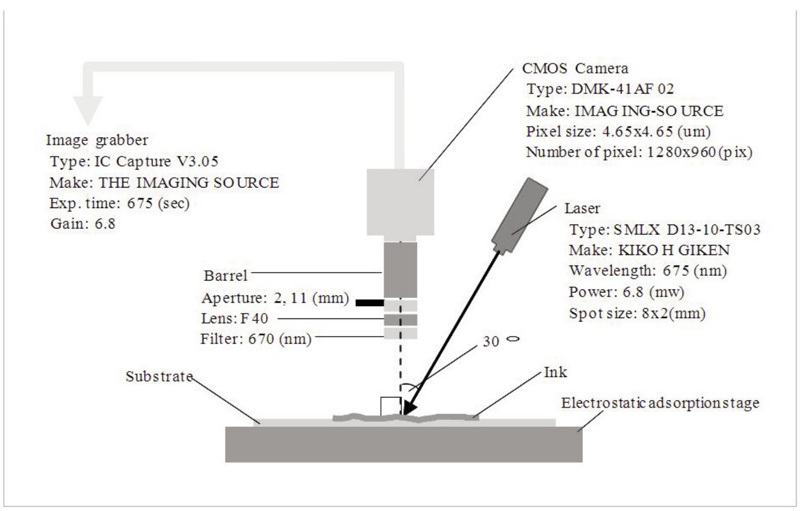


Figure 3: *Speckle patterns capturing device employed for this study.*

to eliminate minute deformation of measured paper due to change of temperature and humidity.

The procedure for capturing speckle patterns is described as following. Immediately after the ink was drawndown the paper, it was attached on the electrostatic adsorption stage and illuminated by laser. Speckle patterns were captured every 10 seconds. The speckle images were saved as BMP image format (256x256 pix, Mono-8bit). For calculation purposes, smaller image size of 128x128 and 64x64 were cropped and saved from the original files.

One of typical indexes, correlation coefficient, was used for evaluating temporal change of speckle patterns. Two successive image data p and q of speckle patterns captured at every 10 seconds are represented in following equations (1) and (2).

$$p = (p_1, p_2, \cdots, p_N) \quad (1)$$

$$q = (q_1, q_2, \cdots, q_N) \quad (2)$$

Where, N is the total number of pixels for an image data. The correlation coefficient R (p, q) is determined by the following equation

$$R(\mathbf{p}, \mathbf{q}) = \frac{\sum_{i=1}^{N} (p_i - \bar{p}) \cdot (q_i - \bar{q})}{\sqrt{\sum_{i=1}^{N} (p_i - \bar{p})^2 \cdot \sum_{i=1}^{N} (q_i - \bar{q})^2}} \quad (3)$$

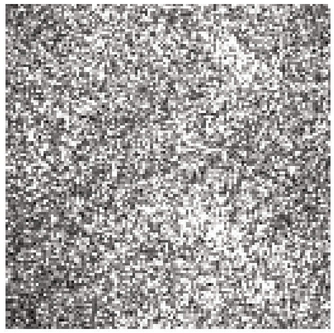
Where, p q are average values of total elements for p, q.

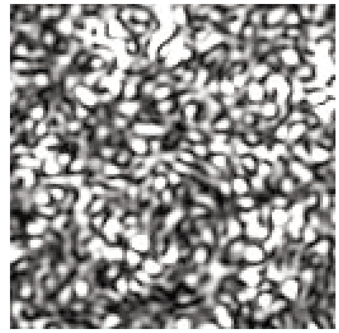
When *R* was plotted, it was averaged with every 6 points (60 sec). If *R* is saturated, which represents the stationary state of temporal speckle change, the ink film is considered as dried.

Results and Discussions

Preliminary Tests

Adequate aperture size of camera and image size for monitoring dynamic speckle patterns were determined before the experiments were conducted. The speckle size becomes smaller as aperture size of camera increases. However, the interference light from wider area striking into CMOS sensor could cause more complicated speckle pattern. Two speckle patterns captured by aperture size (AS) of 11 mm and 2 mm were examined. The results were shown in **Figure 4**. The images showed that speckle size captured at AS = 11 mm was finer than the on captured at 2 mm aperture size.



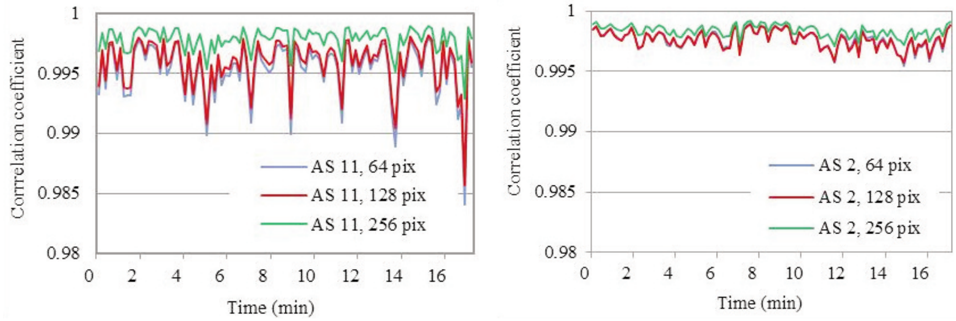


AS = 11 mm *AS = 2 mm*

Figure 4: *Speckle patterns captured at different aperture sizes (AS). The image size was 128x128 pixels.*

Figure 5 (a) showed the result of monitoring correlation coefficient without moving the average of speckle patterns. The laser illumination was from the surface of matte coated paper. Aperture size was set at 11 mm. Image size was set at three levels of 64, 128 and 256 pixels. **Figure 5 (b)** showed the result of correlation coefficient at aperture size of 2 mm with same image size of **Figure 5**. The averages and standard deviations for each aperture size and image size were shown in **Table 1**. The standard deviation of correlation coefficients at aperture size of 2 mm were less than a half of the one derived from aperture size of 11 mm. With narrowing interference area of inspected in some degree improved the temporal stability for optical setup and the paper. Aperture size of 2 mm was set for this study hereafter. Regarding the image size, the standard deviation of correlation coefficients was smaller when calculated with smaller image. Regarding the effect of moving average and computing cost, the image size of 128 pixels was adopted in this study. The choices were determined based on the achieving lower standard deviation of the correlation of coefficient and lower computer cost.

Figure 6 shows temporal change of correlation coefficient for every 10 sec frame with six points moving average. The images were captured after 0.5 ul of 70% alcohol (a) and water (b) dropped by micro pipet on the surface of uncoated inkjet paper, matte coated inkjet paper, and multi-purpose office paper. All of curves in **Figure 6** showed decrease and saturation of correlation of coefficients after a certain period of time. It was prospected that the time from zero to a decreased point at the beginning was for absorption of sample liquid to paper. Absorption and drying times for all levels are shown in table 2. Longer times of absorption and drying on mat coated were supposed that penetration or spread of sample liquids were disturbed by the coated layer comparing other paper variety.

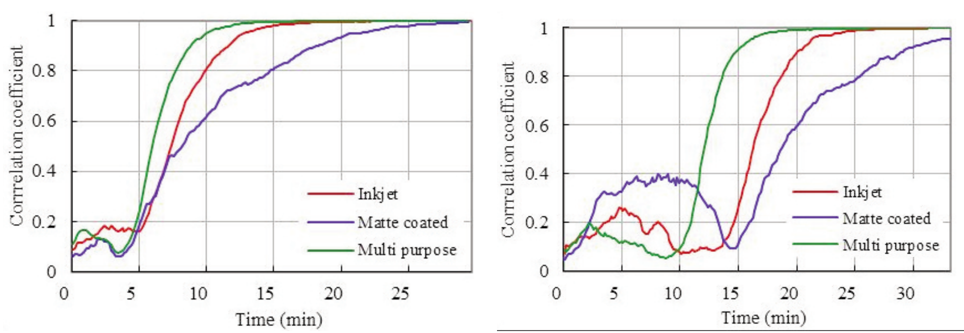


(a) AS 11 mm *(b) AS 2 mm*

Figure 5: *Temporal change of surface of matte coated paper captured with different aperture sizes.*

	Aperture size: 11 mm			**Aperture size: 2 mm**		
Image size (pix)	64	128	256	64	128	256
Average	0.9954	0.9959	0.9978	0.9977	0.9977	0.9984
Std. deviation	0.0023	0.0020	0.0010	0.0008	0.0007	0.0005

Table 1: *Standard deviations and averages for correlation coefficients at different aperture sizes and different image seizes*



(a) 70% alcohol *(b) water*

Figure 6: *Correlation of coefficients of sample liquids on three types of paper surfaces. The elapsed time was determined as drying time in minutes.*

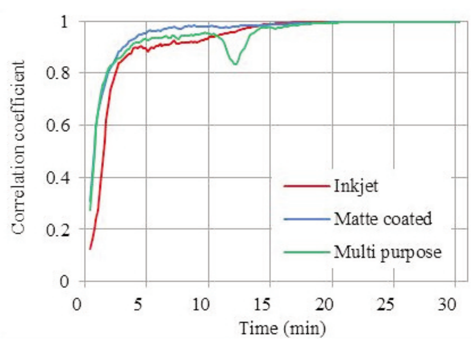
Comparing Inkjet Ink Drying with ASTM F2498-05 Standard Testing Method

Figure 7 shows temporal change of dropped inkjet ink at 0.5 ul on different types of papers. The procedures were the same as for alcohol and water. The surface tension is notably low, hence a time of penetration wasn't observed at every 10 (sec) capturing.

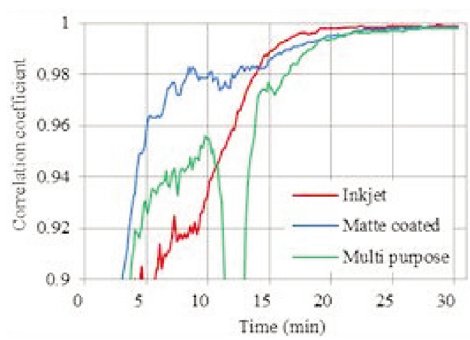
Drying times for different types of papers were shown in **Table 3**. The drying time derived from laser speckle method and the ASTM F2498-05 showed the similar trends. The ink dries slower on the multipurpose office paper than on the uncoated inkjet paper. However, the drying time determined by ASTM method was shorter than the ones of laser speckle method. ASTM F2498-05 is a subjective testing method. The drying time is determined by visual assessment of smudged ink film. This method may not reveal the exact drying condition even after the smudged ink film is not observed.

Paper Types	Alcohol (Absorption , Drying)	Water (Absorption, Drying)
Inkjet	5, 22	12, 31
Matte coated	3, 30	14, Over 33
Multi-purpose	3, 17	8, 24

Table 2: *Absorption and drying time in minutes for 70% alcohol and water*



(a) Whole range



(b) 0.9 and above

Figure 7: *Temporal change of inkjet ink surface on different types of papers.*

Paper Types	Drying time (min)	
	Laser Speckle Method	ASTM F2498-05
Inkjet	22	1.3
Matte coat	25	2.4
Multi-purpose	27	4

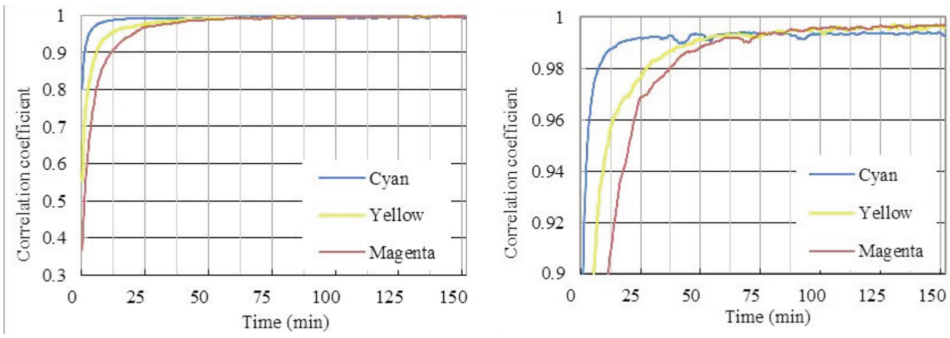
Table 3: *Drying time for inkjet ink determined by laser speckle method and ASTM F2498-05.*

Comparing Offset Inks Drying with JIS K5701-2000

Lithographic inks were drawn by hand on wood free paper (BW 64 g/mm^2, Hakuro, Kisyu seishi) with metal scraper. **Figure 8** showed the temporal change of surface of drawndown cyan, magenta, and yellow inks (DIC Values-G, Dainipon Ink and Chemicals, INC.). **Table 4** showed the drying time cyan, yellow and magenta inks determined by different methods.

In addition to this, the similar samples were under tested using smudge method. Ink films were swiped with cotton swabs by hand every 30 min after drawndown to evaluate the drying time. The drying time is determined when transference of undried ink to cotton swab was no longer visible. The results were listed in **Table 4** as well.

After the ink film was considered to be dried based on laser speckle method, even the dynamic change of speckle patterns was terminated, fractional ink smudge on cotton bud could still be recognized.



(a) Whole range *(b) 0.9 and above*

Figure 8: *Temporal change of drawndown lithographic ink films on wood free paper.*

Inks	Drying time (min)	
	Laser Speckle Method	**Smudge Method**
Cyan	75	300
Yellow	107	300
Magenta	138	210

Table 4: *Drying time for lithographic inks determined by laser speckle method.*

Same printed inks were tested on the Ink Drying Tester Type C. **Figure 9** showed the lines on the tracing paper transferred from the JIS K5701 with Type C tester. For yellow ink, tint transference lines of ink were difficult to be recognized. The transference lines were filtered by complimentary color filter on a flatbed scanner. In **Figure 9**, the point on the time scale that did not show transference line was circled in red and represents the actual drying time. **Table 5** showed the dying time of each ink film. The results showed no significant correlation to the result in **Table 4**. The conventional contact method for determining drying time includes mechanical behavior of ink film and the reception of ink on tracing paper. The transferring property of un-dried ink film to another media should be taken into consideration.

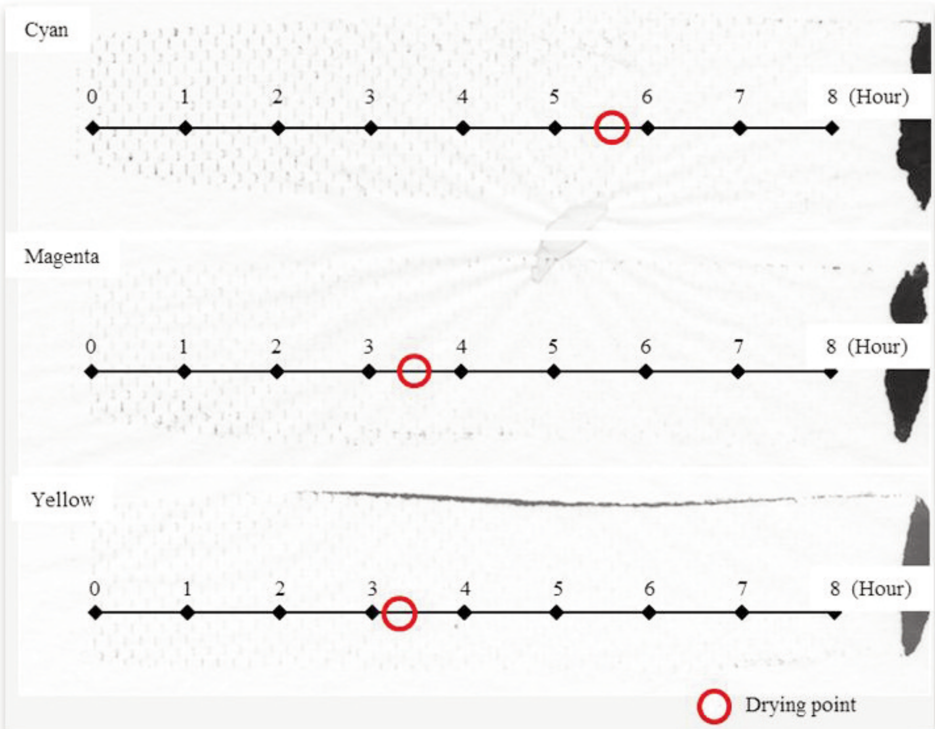


Figure 9: *Displacement inks on a sheet of tracing paper with complementary color filter*

Inks	Drying time (hour)
Yellow	3.2
Magenta	3.5
Cyan	5.6

Table 5: *Drying time for offset inks determined by JIS K5701 method.*

Conclusions

In this paper, we discussed the method to determine the drying time of inks or monitor liquid penetration on paper using dynamic speckle patterns. The laser speckle image of microscopic surface of samples was captured at proper optical set up, aperture size, and image size. The images were used for determine the drying time by calculating the correlation of coefficient. The system presented has the advantage of making objective judgment. The testing system is nondestructive, noncontact. The testing method is simple and quick compared to conventional methods.

As comparison, results derived from ASTM F2498 method for determining inkjet ink drying time on different types of paper showed the similar trends with the drying time determined by laser speckle method. In the meantime, there was not a good correlation with JIS K5701 method or smudge method for determining drying time of lithographic inks. This may be the result of drying difference between lithographic ink surface drying and inner body drying. The conclusion reflected that the presented dynamic laser method is limited to measure surface drying of ink film. To study the inner ink film drying, transmitted speckle patterns could be investigated.

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