Enhancement of flexographic print quality on bleached kraft liner using nano-silica from rice husk

N. Tipsotnaiyana [a], L. Jarupan [b,*], S. Noppakundilograt [c]

[a] Department of Printing and Packaging Technology, King Mongut's University of Technology Thonburi, Bangkok 10140, Thailand
[b] Department of Packaging and Materials Technology, Kasetsart University, Bangkok 10900, Thailand
[c] Department of Imaging and Printing Technology, Chulalongkorn University, Bangkok 10300, Thailand

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ABSTRACT

Nano-silica from rice husk (nano-RHS) was synthesized and used in a coating agent to enhance the flexographic print quality of bleached kraft liner. The rice husk was refluxed with a 2 M HCl solution and calcined in a muffle furnace at 650 °C for 4 h. The particle size of the resultant rice husk ash was reduced to a very fine nano-RHS by hexadecyl trimethyl ammonium bromide. The synthesized nano-RHS in different proportions – 1%, 2%, 3%, 4% and 5% (w/w_{resin}) – was added to a water-based coating agent consisting of acrylic resin. The coating agent with nano-RHS additive was applied by gravure rolling onto the surface of a 170 g/m^2 bleached kraft liner 3–4 μm in thickness. The flexographic print quality was determined with printing details of 31.5 lpc using water-based process colors. The results indicated that the coating agent with 1% nano-RHS was the most promising for improving the flexographic print quality on the bleached kraft liner. At this fraction, the best print quality in terms of high sharpness of fonts and texts, line art, realistic image, and TVI curve (under the requirements of ISO 12647-6) were achieved. In addition, low tone-value and ΔE^*_{ab} with a large, three-dimensional color profile and the widest color gamut were obtained.

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1. Introduction

Corrugated paperboard is one of the most widely used packaging materials, and has been employed for the distribution and transportation of products in almost every industry. It is usually made by the kraft process, and consists of two major components: liner (top and bottom) and corrugated medium. In general, kraft liners outperform any other paper type in terms of strength and toughness. As a result, it is typically chosen for grocery bags and corrugated boxes and containers to transport and deliver products.

Currently, corrugated containers made of kraft liners are graphically printed by means of flexography. However, the rough surface of kraft liner allows for an excessive penetration of inks into the paper structure; this may result in poor print quality, such as indistinct and blurry images. Consequently, most of the graphics that are printed on kraft liners of corrugated containers consist of lined patterns and simple images. Detailed and complicated images, including small-size fonts, may not be printed in good quality on such rough-textured paper. However, enhancement of print quality

on the rough surface can be accomplished if a coating is applied on the paper surface [1]. Coatings using a thin homogeneous polymer film and corresponding surface modification by corona treatment greatly increase the water wettability on the coated paper. The increase of surface energy leads the coated polymeric film on the paper substrate allows the water-based ink vehicle to penetrate into the paper structure while the ink pigment adheres onto the paper surface [2–7].

Silica (SiO_2) has been used for several different industrial purposes: as an absorbing agent, additive, pigment, filler or abrasive [8–10]. Although silica can be obtained from various sources [11], one abundant source of silica is from rice husk. Several studies have been performed on preparation techniques and characterization, including the potential and limits of very fine particles such as rice husk silica. Silica from rice husk can be obtained by a chemical treatment using an acidic HCl solution and incineration at 600 °C under static air and flowing atmospheres [12]. The resulting silica particles obtained are not only pure and amorphous, but also present homogeneous particle size distribution with high specific surface area.

Nano-silica can be prepared by several methods, including vapor-phase reaction, sol–gel and thermal decomposition techniques. An ultrafine or nanoscale silica has potential uses in the

* Corresponding author. Tel.: +66 25625059.
E-mail address: lerpong.j@ku.ac.th (L. Jarupan).

ceramic and construction industries. A uniformly nano-structured silica can be achieved by a nonisothermal decomposition technique which provides the silica with high surface area [13]. The technique consists of burning the rice husk at a very high temperature and pressure; this yields 30% ash which consists of more than 95% ultrafine silica by mass, with minor amounts of metallic elements. A lean-combustion process in a bubbling and atmospheric fluidized bed reactor is introduced to vaporize hot gaseous CO, CO_2, NO_x and amorphous silica [14]. Nevertheless, silica extraction is favored by the effect of lower temperature (<700 °C), yielding an amorphous siliceous material with low carbon content (<3.5%).

Other potential uses of nano-silica include its employment as an additive in coating agents for paper and paperboard during the pre-printing process. One major factor affecting print quality is the nature of the paper surface, where the ink demand and ink pigment penetration increase as the surface roughness increases [15]. With application of a nano-silica coating, the print quality on the paper substrate can be improved. However, the concentration of nano-silica intended for use in the coating should be limited (<5%); also, the nano-silica must contain high whiteness, and the particle size should be smaller than 5 μm in order to yield better print quality [16,17].

Earlier studies indicated the potential use of silica from rice husk as a coating agent to enhance the print quality of kraft liner. The characterization of fine silica powder and the effects of synthesized silica in coating bleached kraft liner for inkjet printing have been studied [18,19]. The silica coating results in good printability, vivid colors and sharper characters as well as images are achieved due to better reception of inks by the paper structure. The present study, therefore, continues this development, and aims to use nano-silica from rice husk to improve the flexographic print quality of bleached kraft liners.

2. Materials and methods

2.1. Synthesis and characterization of nano-silica from rice husk (nano-RHS)

Rice husks used in this study were obtained from rice mills in the central provinces of Thailand. The preparation began by washing and drying the rice husks. Extraction of rice husk silica was performed using an acidic 2 M HCl solution at 80 °C for 120 min before calcining in a muffle furnace at 650 °C for 240 min. The obtained rice husk silica powder was dissolved in a basic NaOH and hexadecyl trimethyl ammonium bromide (CTAB) solution [20]. The pH was adjusted to 10 using HCl and left it for 96 h. The sediment was filtered and washed by 1 M C_2H_5OH before being calcined in a muffle furnace at 550 °C for 300 min to eliminate CTAB until only silica remained; this was then ground in a ball mill. The resultant nano-rice husk silica (nano-RHS) was then used as an additive for the production of coating agents. The characterization of nano-RHS was analyzed, including laser particle size distribution and specific surface area based on the BET (Brunauer–Emmett–Teller) method [21]. The CIE $L^*a^*b^*$ color scale was used to determine the whiteness of the nano-RHS, according to ISO12647-1.

2.2. Preparation of nano-RHS coating agent

To produce a water-based coating agent, the formula for a flexographic coating agent was used [22]. The composition consisted of 80% acrylic resin (Joncryl® 678; BASF, Wyandotte, MI, USA) mixed with 18% distilled water, and 1% antifoaming agent (Foamaster® NXZ; BASF). The obtained nano-RHS from the previous stage was then added as colloidal silica [23] to the coating agent in different proportions: 1%, 2%, 3%, 4% and 5% w/w$_{resin}$. The resultant

coating agents were blended together using a homogeneous mixer; 1% w/w$_{resin}$ disperser (Disperbyk®-193; Byk, Wesel, Germany) was added for better dispersion. The solid content and the viscosity (according to ASTM D7232-06 and D2196-10, respectively) were analyzed. All coating agents with different nano-RHS proportions were analyzed using Fourier transform infrared spectroscopy (FT-IR) with KBr pellet technique [24]. Each coating agent with different nano-RHS composition was applied onto 170 g/m^2 bleached kraft liner by a gravure machine with 23.5 line/cm (lpc) and coating speed of 10 m/min. The coated paper was hot-air dried at 120 °C. The CIE $L^*a^*b^*$ color space was measured by reflection spectrophotometry. Other measurements – including color differences (ΔE^*_{ab}) according to ASTM D2244-11, water absorption according to TAPPI T441, and surface analysis by scanning electron microscopy (SEM) – were also made.

2.3. Evaluation of print quality

Print quality was determined by a standard printing test with a flexographic printer (model FB-200; Nilpeter, Slagelse, Denmark) on a template with detail of 31.5 lpc using four water-based process colors, i.e. cyan (C), magenta (M), yellow (Y) and black (K), and a doctor blade analog roller with detail of 195 lpc and speed of 1800 m/h. The measurements of print quality were: color density, according to ASTM D7305-08a; printing sharpness; ability to display the details of printed material, using a microscope with 50–1000× magnification; and dot area, as measured by a reflection densitometer. The tone value increase (TVI) was calculated from dot area. The ability to display printed colors was analyzed by a three-dimensional color profile made using an X-Rite i1 Profiler (Grand Rapids, MI, USA). Other measurements included CIE $L^*a^*b^*$ on a TC 3.5 CMYK test chart in comparison with the color gamut of the widest printing job using an X-Rite Profile Editor. Printing color differences were compared with flexographic printing standards [25]. Abrasion resistance testing was also conducted using a Sutherland rub tester with 1.81 kg pressure for 10 strokes at a speed of 42 cycles/min.

3. Results and discussion

3.1. Characteristics of nano-RHS and the subsequent coating agents

The appearance of obtained nano-RHS was a very fine white powder. The CIE $L^*a^*b^*$ was reported as L* = 95.64, a* = +0.52, b* = +0.87 and whiteness = 86.47. Analysis of laser particle size distribution and specific surface area, calculated using the BET method, showed that the nano-RHS particles were 11–12 nm in size and the specific surface area was 226 m^2/g. In addition, it was found that the obtained nano-RHS contained numerous small pores due to new organized structures initiated by the CTAB, which acts as a structure-directing agent, resulting in better dispersion and greater specific surface area compared with nano-RHS from a normal extraction.

After adding nano-RHS in varying proportions (1%, 2%, 3%, 4% and 5% w/w$_{resin}$), the resultant coating agents became yellowish in color. The FTIR spectra indicated various functional groups as shown in Fig. 1. The spectra exhibited (respectively) strong peaks at 700 cm^{-1} (representing styrene), 762 cm^{-1} (which can be assigned to the vibration of C=O [ester]), 1405 cm^{-1} (CH_2), 1452 cm^{-1} (the peak of vibrations of CH_2), 1553 cm^{-1} (C=C stretch), and 1635 cm^{-1} (the peak of the OH group) [26,27]. In addition, the functional group of silica in the nano-RHS coating agents showed strong peaks at 552 cm^{-1} (SO_2 rocking), 1030 cm^{-1} (asymmetric Si—O—Si stretching), 1089 cm^{-1} (Si—O—Si) and 1100 cm^{-1} (Si—O—Si stretching)