Ink Enables Increased Efficiency in Flexographic Printing

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Abstract

The current trends in the converted flexible packaging market include increased demand for recyclability, compostability, bio renewable content, reduction in materials and increased production efficiency while maintaining high performance and eye-catching aesthetics. Increased competition and raw material costs have put pressure on both the top and bottom lines making the search for operational efficiencies a matter of priority. A novel ink formulating approach was taken by Flint Group and tested in commercial applications, which increased efficiency as well as enabled high print fidelity at increased press speeds. Our patent-pending formulating approach and ink compositions that enabled reduced cob webbing and plate build-up, improved ink transfer, print fidelity, and color density are discussed in the context of the aforementioned trends and press room benefits.

Introduction

Flexible Packaging Market

Packaging was developed and used for the purpose of transportation, storage, and protection for everyday goods, and since become the primary tool to drive consumer decisions and build brand connections. The flexible packaging association (FPA) defines a flexible package as any package or part of a package whose shape can be readily changed (FPA, 2010). Furthermore, the FPA defines the flexible packaging segment to be value-added packaging, retail poly bags, consumer products such as trash, storage bags and wraps, and other poly bags and wraps. According to U.S.

Census Bureau and the FPA, the flexible packaging sales in 2011 was approximately 25.4 billion US dollars; and the value-added packaging segment, which is characterized by multiple converting processes such as printing, extrusion and lamination, is estimated to be 19.6 billion US dollars (FPA, 2012).

Increased competition and raw material costs have put pressure on both the top and bottom lines making the search for operational efficiencies and reduction in raw materials a matter of priority. Filmic substrate development for the flexible packaging market is driven by market trends, package designers, converters, and consumer product companies. Current trends in the converted flexible packaging market are to design packages that meet sustainability requirements while presenting to consumer greater convenience, safety, and quality. The increasing demand for sustainability and growing interest in reducing dependence on petroleum-based products, drives new filmic substrate development in the areas of bioplastics, biodegradable, recyclable, and compostable film and barrier coating. Down gauging of films also minimizes the environmental impact of excessive packing. Aesthetics improvements to provide packaging “eye-catching” graphics, appealing color, and increased special effects is the key to establishing a relationship with the consumer which results in a purchasing decision. At the mean time, package is expected to provide convenience, product freshness, and multi-functionality, which may include microwavable, cook-in-bag, and re-sealable. Additionally, operational efficiency is a much discussed topic these days. The current trends in the flexible packaging market can be summarized under the main categories: sustainability, aesthetics, functionality, and efficiency, or S.A.F.E.

The value-added packaging segment is the largest segment of the flexible packaging market and the value delivery system is well known. The converter acts as the integrator of consumable materials and hardware. Pigments, resins, and solvents are converted into inks which are printed on substrates using plates and anilox rolls mounted on presses which are then turned into packages and filled by consumer product companies which in turn are shipped to retail outlets to be purchased by consumers. Raw materials costs have a considerable effect on the flexible packaging industry in terms of end user pricing. The implications of rising costs are felt all along the entire value delivery chain. Moreover, the volatility of crude oil prices and other petroleum feed stocks are having a major effect on package costs, both in raw materials and transportation. The World Bank commodity price indices indicate that raw material costs in 2011 were about 15% greater than those during the previous peak in 2008 (World Bank, 2013). Therefore; integrators in the converted flexible packaging value chain require increased efficiency in their process from all partners in the chain continuing to supply improved aesthetics.

Flexographic Printing in Flexible Packaging

Flexographic and gravure printing are two competing primary printing processes in the flexible packaging market. The two processes each have their own advantages. Gravure printing process is known for its simple handling, robustness, consistence, and high print quality; flexographic printing is said to be faster changeovers, more cost effective, and have the capability of handling thinner gauges of elastic material. In recent years, great flexographic technological advancements have been adopted in every area of the process and are leading the flexographic printing quality towards gravure and offset quality. Consumer marketing was also changing from mass-marketing to more specific matching of product packaging to consumer characteristics, resulting in shorter runs, a trend that obviously favored flexographic over gravure. Flexographic printing prevails in North America and has gained great interest and progress globally in the flexible packaging industry.

A typical flexographic printing system uses an enclosed doctor blade and a rubber roll that picks up the ink and transfers it to an anilox metering roller having engraved cells. The ink fills the engraved cells. The ink is transferred in a uniform layer from the anilox roller to a rubber or photopolymer plate that has an image raised in relief and recessed non-image areas. A final transfer of the image then occurs from the plate to the substrate. The process is shown in **Figure 1**.

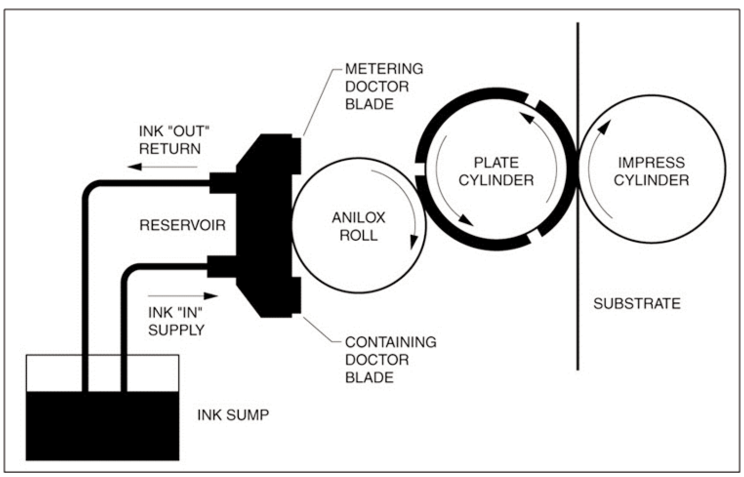

Figure 1. *Schematic representation of a flexographic central impression (CI) printing press (Sneary, 2004)*

Flexographic printing involves physical contact between ink and plate and between ink and substrate. Print quality is influenced by factors including film surface, machinery configurations, and ink chemical parameters. Surface properties of substrate affect how well ink is being accepted onto the surface. The configuration and geometric of the cells in the anilox roller and the pressure between the anilox roller and the doctor blade control the amount of ink retained in the anilox roller and therefore available to be transferred to the printing plate. The press speed, ink properties, and the plate material controls how well ink is being received on the plate and there transferred to the substrate forming the graphics.

Driving Forces for High Definition (HD) and High Speed (HS) Flexographic Printing

Studies have shown that consumers buy products for the first time with high visually appealing graphics. These purchase decisions and behaviors force consumer product companies to create impressive graphics that can capture “eyes” and subsequently establish a value connection between the consumer and any given brand. Flexographic printing has achieved great success in recent years and grows to the point where it is the most popular packaging printing process in many print segments globally. However, conventional imaging technologies have reached their limits to give further atheistic improvement for brand differentiation. The process failed to produce a smooth screen vignette down to 0% ink coverage and the printed images lack sharp details and often show abrupt tonal value jumps. HD imaging technologies were developed to meet the needs to produce graphics with smooth vignette, intense color, high contrast, and sharp detail and truly close the gap between flexographic and gravure printing. Developments in HD flexographic printing or improved print fidelity in the flexible packaging market are driven by increased demand for impressive eye-catching graphics that help position the brand and connect the consumer to the brand’s primary value proposition.

Developments in high speed printing are driven by flexible packaging converters as well as consumer product companies upstream in the value delivery chain. Consumer product companies’ commitments for faster turnover, shorter deliver time, and fewer inventories put pressure on converters to increase their operational efficiencies. Rising raw material costs and the ever present demand for increased profitability also force converters to examine and indentify all aspects for increased efficiencies. Converters are beginning to recognize the opportunities and challenges of higher printing speeds in capturing their entitle values and push this trend along the value chain. High speed printing appears to be an integral part of their strategy for achieving their S.A.F.E. objectives which include achieving less waste, fast changeovers, and reducing energy consumption.

Technology Review

Many factors and enabling technologies are involved in HD and HS flexographic printing and need to be completely integrated at the converter level to achieve success. Consumable suppliers including aniloxes, plates, films, and inks along with machinery suppliers are the main value chain participants and they all work to align offering faster speed consumables for the flexographic printing industry. New flexographic printing presses are designed with high speed infrastructure in mind. The VISTAFLEX serial from Windmoeller & Hoelscher (W & H) prints at a maximum speed of 800 m/min (2624 ft/min) and is equipped with robotic sleeve or anilox handling systems, automated job change-over system, and computer control system that organizes and runs production quickly and optimally. Fischer & Krecke (F & K) 30SIX CI flexo press also speeds up to 1,000 m/min (3,281 ft/min) and provides increased production output and premium print quality.

New plate technologies that allow immediate image process while providing fine line graphics at high speeds are introduced by Flint Group, DuPont, and Kodak. Flat-top dot that resists wear, high imaging resolution and image fidelity, micro-fine plate surface are the key attributes of high definition flexo plates and deliver improved ink transfer efficiency. Flexible packaging printers that have introduced high definition plates into production are reporting a reduction in make-ready time and materials, improvements in press run speeds, and plates that last longer. New development and research in anilox and doctor blade also promotes higher speed in flexo printing. For example, Apex's GTT anilox technology delivers the right amount of ink from two types of anilox surfaces whether it is for fine screen or solid printing which facilitates high speed printing. Daetwyler has developed doctor blades ready for quick start-ups, which can provide thin ink film associated with fine line aniloxes as well as protect the thin cell walls present in the anilox engraving.

With new machinery technologies and consumable supply technologies including plate, anilox, and film have been aligned their value propositions in high definition and high speed printing, ink technology is becoming the key technology to handle increasing graphic variability and enable higher operating speeds in flexographic printing. Printing ink is a very small part in the flexible packaging industry; however, it is highly visible and allows packaging designers to create impressive graphics and multi-functional packaging. To align with the new development and research in flexo press, plate, anilox, and blade technology and meet the S.A.F.E. in flexible packaging, new ink formulations need to be designed with HD and HS printing strategy in mind.

Ink Formulating Principles

Many factors contribute to ink transfer in flexographic printing process and in turn the final print quality. Filmic substrate including polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), and polyester (PET) are widely used in the flexible packaging industry. Other films like nylon, metalized films, as well as oxide-coated films are also used to enhance barrier properties of flexible packaging. The surface chemistry and surface energy level of these nonporous substrates affect how well an ink is accepted and spreads, and eventually the graphic quality. Today, many surface treatments including chemical, corona, flame, and thermal treatment and surface grafting are used to increase surface energy and improve wetting and adhesion. Process configurations are also important to achieve success. The list of factors that may affect printing quality is shown in **Figure 2**. It is readily apparent that ink plays an important role on the final quality of graphics and provides the viability and consistence in flexographic printing. Printing ink formulations must meet all end-use functionality for the flexible packaging and couple waste reduction initiatives while also handling increasing graphic variability of package and higher operating speeds.

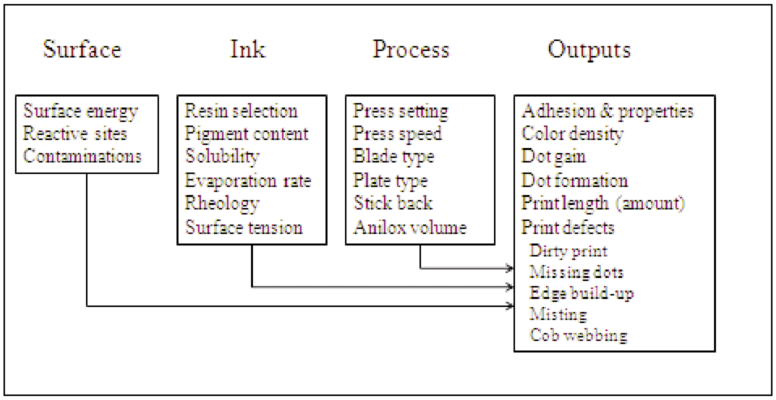

Figure 2. *Factors that may affect print quality in flexographic printing*

Printing is a dynamic process with multiple factors involved. Solubility, inks surface tension, ink elasticity, solvent evaporation rate, and press conditions all play a major role in the process. Ink printability is measured by color density, dot formation, print cleanness, and print length. Printing defects, such as misting, edge build-up, cob-webbing, missing dots, or dirty print, cause press downtime, material waste, and more energy consumption. Poor printability is the result of poor ink transfer on and off the plate. Polymer solubility and ink properties such as ink elasticity and ink tack affect ink-ink splitting and ink transfer and these characteristics can be modified through resin and solvent selections. Efficient ink transfer is the most important element in driving press efficiency benefits for wide web flexographic printing, especially on filmic substrates.

Results and Discussions

Printing defects

Flexographic printing speeds are expected to increase and as printing speeds increase, the printability of the ink begins to deteriorate and print defects can be observed with conventional ink technology. Cobwebbing is one of the common printing defects and describes a problem of printing processes in which a filmy, web-like build-up of dried ink or clear material on the doctor blade, or on the ends of impression rolls according to GAA (Gravure Association of America) and FTA (Flexographic Technical Association). Dirty print is an appearance of a dirty or grainy effect in the process areas as a result of two or more process dots linking together by inks. Dirty print is an indication of poor ink rheology or ink drying too fast resulting in poor ink transfer. Dirty print can also be caused by incorrect relationship between print plate dots and anilox line screen cells. If the dot on the print plate is smaller than the cell on the anilox roll, the dot can actually enter the anilox cell, picking up excess ink. This is referred to as “dot dipping” and can lead to very dirty printing situations. Excessive plate impression, worn doctor blade, or press room conditions can also cause dirty print.

Misting is another main printability problem at high speed printing in which small airborne droplets or filaments of ink are ejected from the rapid rotating roller of the printing machine. This phenomenon not only causes waste in ink, film, energy, and decreases production efficiency, but also represents an environmental or health hazard to workers in the printing industry. Edge build-up is a term used to describe a printability problem that ink is drying along and building up on plate edges and type edges, primarily on the trailing edge of the image area. Presses need to be stopped for plate clean up when edge build-up is too heavy and interfering with the complete transfer of ink from plate to substrate resulting in a ragged and feathery appearance. Other possible printing defects at high speed printing include pinholing, ink smearing, and ghosting.

Printing defect is one of the main causes leading to downtime in production; it also results in material waste and energy waste. At higher printing speeds, everything on press happens faster and therefore less time available for ink-ink splitting, leveling, and spreading. Ink-ink split behavior and ink spreading are the key factors controlling print quality. The inability of conventional ink to split and wet the plate and substrate surface under shorter time is the main reason of poor ink transfer. New ink technology must be developed to eliminate these defects and enable printers to print at a higher speed and for longer runs.

Hard/soft segment ratio

Ink technologies used in flexographic printing can be water based, solvent based, and ultraviolet (UV) curable ink. Solvent based inks are most widely used in flexographic printing since these inks dry fast, perform well, offer excellent graphic quality, and allow printers use a wide choice of non-porous filmic substrates. Solvent based inks for flexographic printing are well established and many resin technologies such as polyamide, polyurethane, acrylic, polyester, PVB (polyvinyl butyral), nitrocellulose, etc. are used to meet adhesion and end-use requirements. In general, these inks contain pigments, organic solvents, resinous binders, waxes, and additives if needed.

The hard/soft resin ratio is critical in controlling ink elasticity. Most of the polymers used in ink formulations have two transition temperatures: the glass transition temperature, T_g, which corresponds to the amorphous region and is a continuous transition; and the melting temperature, T_m, which corresponds to the crystalline region and is a sharp transition. "Hard" and "soft" polymer is a relatively defined terminology which is based on a polymer's transition temperatures. A "hard" resin is defined with a T_g above ambient room temperature and this type of polymers have been known to impart low extension viscosity; and a "soft" resin is normally has a T_g below room temperature and is known to impart high extensional viscosity. Elasticity of a polymer behaves the similar way as its extensional viscosity, thus combining two classes of polymers, soft and hard polymers, at a certain ratio can achieve desired printability.

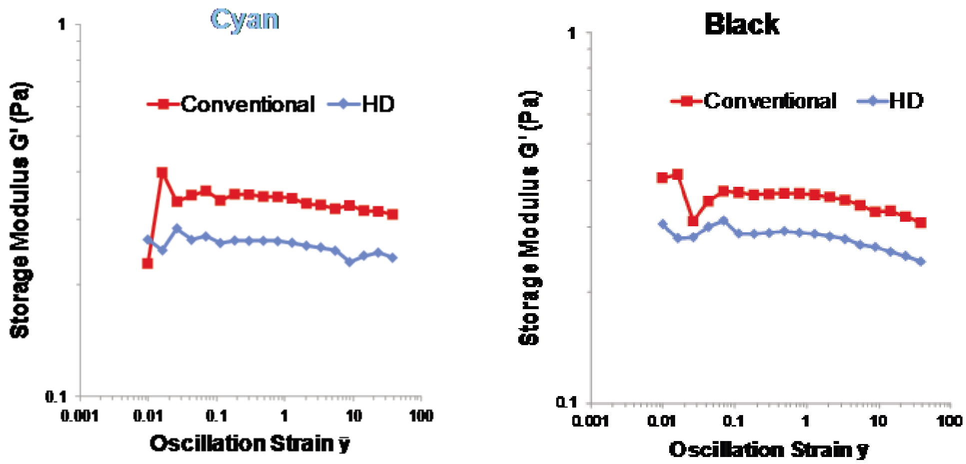

Figure 3. *Ink elasticity comparison*

Ink elasticity

As ink film exits the anilox or printing plate roll nip, ink-ink split undergoes via cavitations and filament formation. The filaments then elongate and break up as the two cylinders continue to separate. The elasticity of an ink and the printing speed determine the degree of misting in flexographic printing. Changes in polymer structure, T_g, molecular weight, polymer solubility, pigment content, or degree of pigment dispersion have a significant effect on ink elasticity and in turn result in changes in ink split and transfer behavior on press. A study performed by James (2003) concluded that an ink with higher elasticity in extension is more prone to misting in printing.

Ink elasticity was measured using a Bohlin Gemini 200HR Nano Rheometer with a C25Din53019 rod at 25º C. Solid-like property or elasticity of a material is usually expressed in the storage modulus G'. It can be noted in Figure 3 that the HD inks (cyan and black inks were tested) show lower elasticity than the conventional inks.

Solubility and evaporation rate

Solvent selection of an ink system is important for printability. The choice of solvent involves solubility parameters which indicate the ability of a solvent to dissolve a material and evaporation which represents how fast a liquid evaporates. The Hildebrand solubility parameter is a numerical value that indicates the relative solvency behavior of a specific solvent and it gives even greater accuracy when it is used in conjunction with dispersion forces, polar forces, and hydrogen bonding forces to examine the solubility of solvents. Solvents can be blended to exhibit selective solubility behavior or to control properties such as evaporation rate and solution viscosity. The solubility parameter of a solvent mixture can be calculated by volume-wised contribution of the solubility of individual components of the mixture and can be used to predict the solubility behavior of a solvent mixture. Similar method which averages the Hildebrand values, polar components, and hydrogen bonding values of the group of solvents that dissolve the polymer can be used to indicate polymer solubility. It is very important to formulate a solvent blend that matches the polymer solubility to achieve maximum uncoiling of the polymer molecule. The increase in polymer surface area that comes in contact with the substrate also results in improving adhesion and dried ink film properties.

Solvent evaporation occurs throughout the entire printing process and difference in evaporation rates can shift the solubility parameter of the blend as solvents evaporate. This change must be taken into consideration in ink formulation. If a fast drying true solvent is mixed with a slow evaporating non-solvent, as the true solvent evaporates, the compatibility between solvents and polymer shifts and the predominance of non-solvent during the last stages of drying can result in poor printability of ink.

Surface tension

The cohesive force among liquid molecules is responsible for the phenomenon of surface tension, and the surface energy quantifies the disruption of intermolecular bonds that occur when a surface is created. When a liquid encounters another substance, there is usually an attraction between the two materials. The adhesive forces between the liquid and the second substance compete against the cohesive forces of the liquid. Liquids with weak cohesive bonds and a strong attraction to another material tend to spread over the material.

Inks exhibit both an adhesive force that associates to the substrate and a cohesive force which is self-adhesion of the ink. When an ink comes into contact with a substrate, the transferring and spreading of an ink onto a substrate depends on the surface energy of the material delivering the ink, the surface tension of the ink, and the surface energy of the substrate receiving the ink. An ink needs to have lower surface tension than the surface energy of a substrate to promote good transferring and spreading and in turn facilitates good adhesion to the substrate.

After wet ink film exits and splits at the nip, an important step in obtaining a smooth and uniform ink film on the substrate is leveling, which is under the influence of the ink's surface tension, viscosity, and elasticity. According to Orchard's (1962) mathematical model of the leveling process, low viscosity and a high surface tension favor the rate of leveling. Leveling is especially critical in large continuous solid areas that smooth and uniform ink film is paramount. It needs to be noted that leveling and spreading are two different processes; and the effect of surface tension on spreading is opposite to the effect on leveling. To achieve good spreading, the surface tension of an ink should be as low as possible; however, for good leveling, the surface tension should be as high as possible. In practical applications, a compromise has to be reached to achieve optimum leveling and spreading.

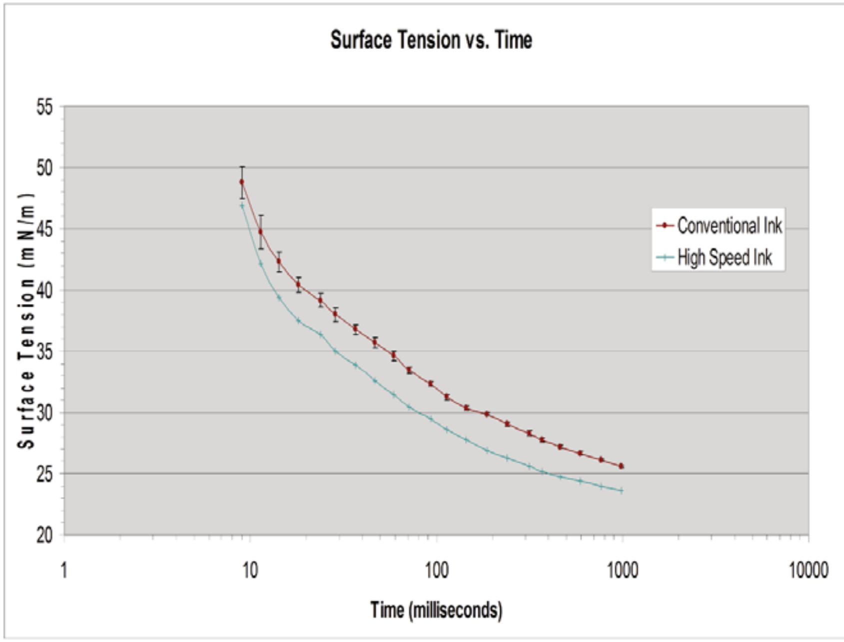

Figure 4. *Surface tension comparison*

Figure 4 shows the measurements of surface tension as a function of surface age of a high speed white ink and a conventional white ink using the maximum bubble pressure method. In high speed printing, new interface is constantly being created and equilibrium surface tension (static) could never be attained; therefore, dynamic surface tension is the more relevant parameter when describing the dynamic behaviors. Solvent based ink formulations have inherently low surface tensions because the solvents used can wet readily and transfer well onto most substrates. The effect of surface tension on the printability of solvent based ink systems is not as critical as the effect on water based ink systems.

HD and HS ink performance

Flint Group's patent-pending High Definition Bases for solvent flexo printing – FlexiBase™ HDP were formulated fully utilizing the principles outlined above. This new base line delivers superior high speed printability and strength, while delivering an exceptional value. Combined with different technology vehicles (surface, lamination, and shrink vehicles), the product line allows printers to use high line screen plates (175 lpi +) and aniloxes (1000 lpi +) making it possible to meet the consumers' insatiable demand for impressive, eye-catching, brand-connecting graphics and increased efficiency.

Four lamination inks formulated using the HD and HS ink technology and four of the conventional lamination inks were printed on corona treated PET substrate with a W&H 10 color CI flexographic press; Dupont DPR plates were used for the trial; anilox was 1000 lpi / 2.7 bcm. The standard operating speed was 1,200 ft/min and the goal was to print consistently without plate clean-up for an extensive length at 1,600 ft/min.

	Ink Press Viscosity (Zahn cup #2)		Color Density		Press Speed (ft/min)		Anilox Volume (lpi / bcm)
	Conventional	HD&HS	Conventional	HD&HS	Conventional	HD&HS	
Cyan	23	23	1.39	1.45	1200	1600	1000 / 2.7
Magenta	22	22	1.28	1.40	1200	1600	1000 / 2.7
Yellow	23	23	0.91	1.00	1200	1600	1000 / 2.7
Black	23	23	1.40	1.50	1200	1600	1000 /2.7

Table 1. *Trial Results*

As shown in **Table 1**, the HD and HS lamination inks achieved higher density at an increased press speed with the same anilox configurations. Color densities of the HD and HS inks are about 10% higher than the conventional inks. These inks performed well at 1,600 ft/min without any plate clean-up for an extensive length which was longer than 350,000 feet. No cobwebbing, misting, or dirty print was observed. With the conventional inks, at 1,600 ft/min, plate clean-up was needed at a short printing period due to dirty print and cobwebbing.

Figure 5 illustrates the quality difference between the HD and HS and the conventional inks, as we can see, the HD and HS flexographic inks exhibited better dot formation which led to better print fidelity and better ink transfer at 1% tone scale. The print sample printed with the conventional inks showed dot bridging, missing dots, and donut shape dots, indicating poor ink transfer.

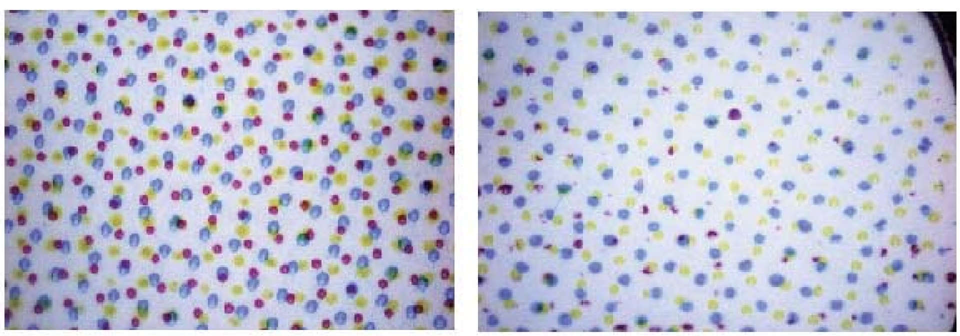

Figure 5. *Dot structure and ink transfer comparison*

The trial results show that the HD and HS lamination ink technology enables the printers to increase their printing speed from 1,200 ft/min to 1,600 ft/min which is a 33% increase in production efficiency and offers better graphic quality. This means less energy consumption, less labor hour, and less waste. It also means reduced raw material costs, improved lead times, decreased inventory, and most importantly increased profitability for printers.

Conclusions

The current market trend in flexible packaging can be summarized as S.A.F.E. High definition and high speed printing is an integral part of converters' strategy for achieving their S.A.F.E objectives; and high definition and high speed ink technology is one of the key element to achieve improved graphic quality and implement high speed printing.

Flint Group's patent-pending high definition and high speed ink technology has successfully achieved improved printability and better graphics at a higher printing speed on a commercial CI flexographic printing press. The effect of the inks on production efficiency was evaluated and the main finding can be summarized as:

- The high definition and high speed ink technology enabled printer to increase operating speed from 1,200 ft/min to 1,600 ft/min - a 33% increase in efficiency;

- Enabled printers to achieve better dot structure with no missing dots - better print quality;

- Achieved higher color densities with the same operating configuration - cost reduction;

- Eliminated dirty print, edge build-up, and cob-webbing, and performed consistently with longer print length - less waste and downtime, lower energy consumption, and increased efficiency.

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