

Hot-melt printing technologies

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New methods and applications which take advantage of the properties of hot-melt print media have been emerging.

Hot-melt printing processes utilize inks that are solid at room temperature. The ink is prepared for printing by subjection to specific heat and/or pressure requirements. The molten ink is then transferred to a target substrate in a discrete pattern to create a hard copy of an image. The actual process may be impact, nonimpact, or noncontact.

The use of hot-melt print media has many advantages, many of which are similar to those realized with the use of hot melts in general. The primary benefit is the elimination of hazardous solvents and waste products. Hot-melt ink products are much cleaner and easier to handle than wet inks, providing a significant advantage to the end user.

There are also several disadvantages inherent in the use of hot-melt inks. These disadvantages primarily result from limitations on ink formulation dictated by the parameters imposed by the particular printing method. Basically, the hot-melt ink must satisfy two critical criteria. First, it must operate in the printing process for which it is intended to generate an acceptable image. Second, the resultant image must satisfy all the performance requirements of the application. Accomplishing both of these goals is the real challenge behind designing hot-melt inks.

Several printing technologies have been developed which take advantage of hot-melt print media. These include large volume commercial operations such as flexographic and screen printing. This article will concentrate on specialized methods used for label printing, industrial marking and coding, and high-quality desktop printing, including correspondence, graphics, and engineering documents.

Impact printing

Impact printing remains a dominant technology used for many office and industrial printing tasks. Simply stated, impact printing involves the transfer of ink from a ribbon, foil, pad, or roller to a target substrate by means of impact from an etched plate, typeface, or hammer. Cold impact printing, accomplished without the addition of heat, is typically used in typewriters, computer printers, and label

1. Typical hot stamping temperatures

Application	Die Temperature
Plastic part	100-250°C
Plastic film	Up to 160°C
Fabric	115-140°C

printers (1). When heat is added, the process becomes suited for a number of specialty printing and decorating tasks, collectively called hot-stamp printing.

Hot-stamp printing

Hot-stamp printing applications include plastic and metal decorating, fabric label printing, pressure-sensitive label printing, and graphic arts. The general process used for decoration of plastics has been reviewed in other articles (2, 3). The conditions under which ink is transferred depend on the substrate being printed or decorated. They include die temperature, pressure, and dwell. Typical printing temperatures are shown in Table I.

The basic hot-stamp process is depicted in Fig. 1. The heated die contacts the back side of the foil, causing the coated side of the foil to impact the target surface. Contact is maintained for the specified dwell, during which time ink melts and is transferred to the substrate in an image defined by the die.

A typical hot-stamp foil construction is shown in Fig. 2. The foil consists of a plastic film base carrier, usually polyester, polypropylene, or polyethylene, with one or more coating layers. The ink or color coat layer contains the image-generating material such as pigment or dye. A release coat may be included to control separation of the color coat from the carrier. A size coat may be used to enhance adhesion of the color coat to the substrate. In addition, a lacquer coat may be added to protect the color coat on the printed article. A metallized layer can be used to impart a metallic finish to the part or label. The thermal and rheological properties of each of these coating layers, as well as the properties of the base carrier, play a major role in the hot stamping process.

Certain criteria must be met for the process to be successful. The temperature of the die must be high enough to melt or soften the ink layer effectively but not melt the base carrier. The dwell time must be long enough to

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provide sufficient heat transfer through the carrier to the ink layer. As the printing cycle is completed and the heat is removed, the ink must solidify instantaneously on the substrate, producing a sharp image. In addition, the resultant print must be resistant to several conditions, including weathering, temperature extremes, abrasion, and exposure to detergents, solvents, and water.

Hot-melt ink roller

A specialty impact printing method found extensively in the packaging industry uses a foam roll impregnated with hot-melt ink as an ink supply unit. Figure 3 illustrates a hot-melt ink roller printer. The hot-melt ink roller is placed into a heated fixture on the printer, which maintains the ink at a temperature above its softening point. A type wheel contacts the surface of the roll, transferring ink to the type. The type wheel then shifts position to impact the surface to be printed. Ink is transferred to the target and solidifies immediately. This cycle can be repeated up to several hundred times a minute. This method is commonly used to apply date and lot codes to various packaged products. The types of surfaces on which printing can be done include polyethylene, polypropylene, polyester, cellophane, coated films, and coated cartons.

Inks used in this process consist of specially formulated hot melts with pigment added to provide print contrast. Operating temperature range of the heated fixture is typically 120°C to 160°C. The ink in the roll actually is exposed to a lower temperature due to convective losses and the insulating nature of the foam.

The key ink property which governs performance is the viscosity-temperature relationship. For a given foam construction and operating temperature, the ink can be formulated to a melt viscosity which provides optimum performance in the roll. This is measured by the decrease in the rate of transfer of ink as it is depleted from the roll. If the ink does not flow sufficiently through the foam to provide an adequate supply at the surface, there will be a noticeable loss of opacity in the prints over time. In addition, the hot-melt ink must perform acceptably once on the substrate. Abrasion and rub resistance are the two most important requirements for packaging applications. The ink must also be resistant to offsetting onto other surfaces even at slightly elevated temperatures.

Nonimpact printing

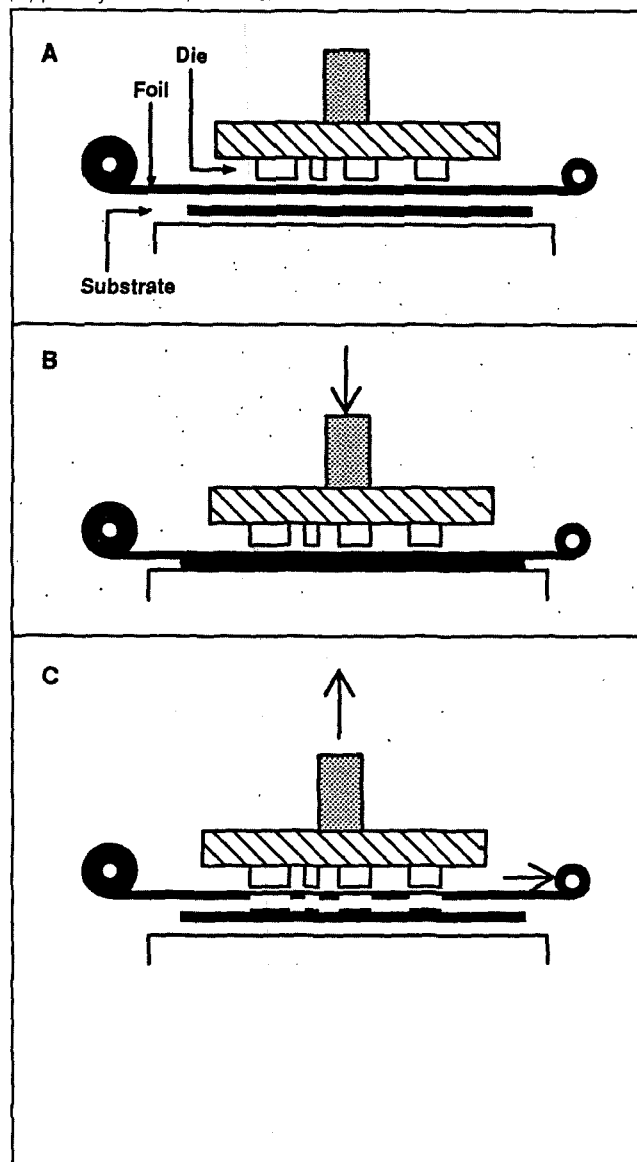
With the continuing evolution of electronic imaging, nonimpact printing has maintained substantial growth in many application areas. As in the processes described above, substrate contact may occur, but the impact action of a pin, hammer, or type is absent. Two examples of nonimpact methods follow.

Thermal transfer printing

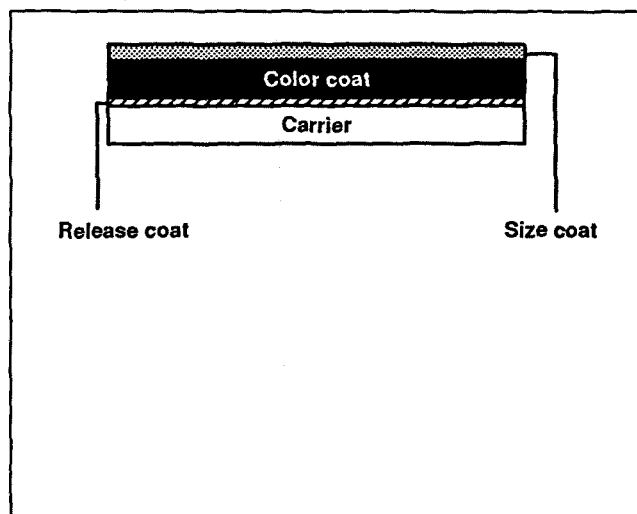
Thermal printing has emerged over the last 20 years to take a position of dominance in many application areas. Such printing processes are commonly used in facsimile machines, recording instruments, point of sale terminals, computer output devices, calculator printers, and label printers.

The original thermal printing processes use special substrates containing a heat-activated colorant. This

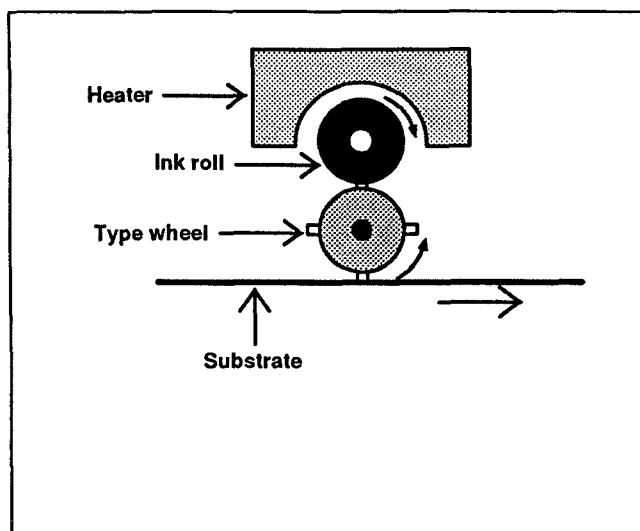
1. Hot-stamp process: (A) system ready to cycle; (B) print cycle begins; (C) print cycle ends; foil indexes



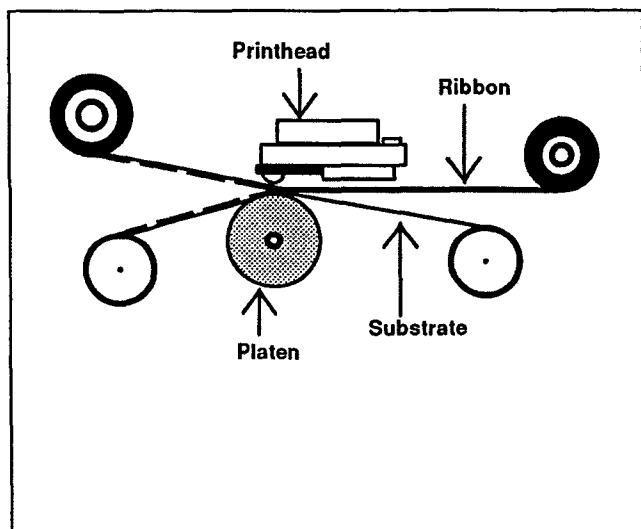
2. Hot-stamp foil construction



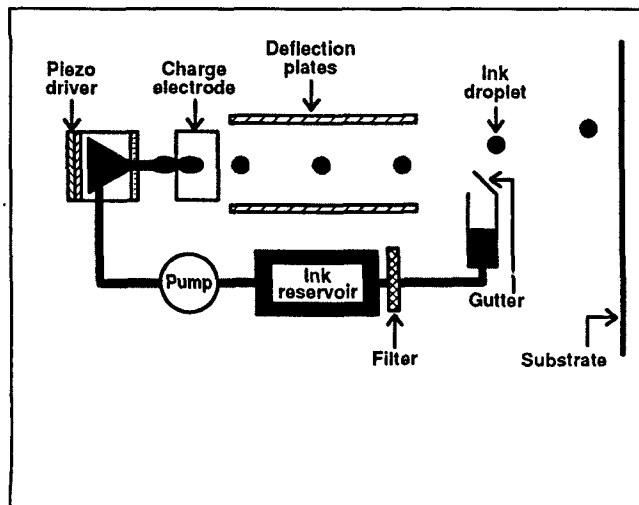
3. Hot-melt ink roll printer



4. Thermal transfer process



5. Continuous ink-jet system



thermal paper passes over the printhead, which selectively heats the substrate to activate the colorant, thereby creating the image. This process, called direct thermal printing, is still in widespread use today. Due to some undesirable characteristics of thermal paper, the development of thermal transfer ribbon ensued in the 1970s.

The thermal transfer printing process is depicted in Fig. 4. In contrast to hot stamping, the image is created electronically through a computer, eliminating the need for dies. In addition, the process is continuous, allowing for faster throughput.

The construction of the thermal transfer ribbon is similar to hot-stamp foil. The ink layer, containing colorant and binder, is coated onto a plastic film, usually polyester. Release and laminating layers may be used to enhance performance. As the ribbon or foil moves through the print area, the back side comes in contact with the thermal printhead, while the coated side simultaneously contacts the substrate. The thermal printhead provides the means to heat the ribbon in discrete areas to transfer ink selectively to the substrate. The printhead consists of an array of heating elements which can reach surface temperatures of 300°C to 400°C and cycle back to ambient within milliseconds.

The thermal properties of the inks have a significant influence on the success of the printing task. Release of ink from the carrier is not achieved until the temperature at the ink/carrier interface reaches the melting or softening point of the ink. The actual temperature to which the ink is usually exposed is 60°C to 120°C. This temperature is influenced by power input to the printhead heating elements, speed of the foil web, and pressure between the foil and substrate. The thermal conductivity of the base carrier is also critical.

Early thermal transfer foils were made with inks composed primarily of waxes and pigment. For applications printing on paper, the properties of these inks are adequate. In recent years, the utility of thermal transfer has expanded into application areas which demand more stringent performance requirements. In addition to producing high-quality images, the ink has to provide abrasion, rub, heat, and/or solvent resistance. As a result, recent development has concentrated on using higher molecular weight resins and polymers. This is a specialized and somewhat novel hot-melt formulating task which holds tremendous potential.

Ink-jet printing

Ink-jet printing technology has been employed in many applications, including computer printing, bulk mail addressing, industrial parts marking, and package date and lot coding. One unique feature of ink-jet printing is that it is noncontact, unlike any of the methods described previously. Droplets of ink are ejected from an orifice and directed through the air to strike the surface to be printed.

The way in which the droplets are generated and how their resultant flight path is controlled depends upon the particular jetting technology used. The two prominent methods are referred to as "continuous" and "drop-on-demand" ink-jet printing.

Continuous ink-jet

In continuous ink-jet printing devices, a stream of conductive ink is pumped under pressure through an orifice, where the stream is broken up into droplets under the influence of a piezoelectric driver element, as illustrated in Fig. 5. The drops pass through a charge electrode which applies a variable charge to each drop. The drops then pass between a pair of high voltage plates and are deflected from their original flight path. The magnitude of the deflection is dependent on the amount of charge deposited on the individual drop. By precise computer control of the charging step and subsequent deflection, the placement of drops on the target is controlled to produce the image. Drops not used for image generation are steered to a gutter to be recirculated through the ink supply.

Inks used in continuous ink-jet devices are typically solvent- or aqueous-based. There are a number of disadvantages inherent in using solvent-based inks, including health and waste issues. Also, the ink must dry quickly on the substrate but not in the printer. Although theoretically possible (4), the use of hot-melt inks in continuous jet printing has not been of any significance.

Drop-on-demand ink-jet

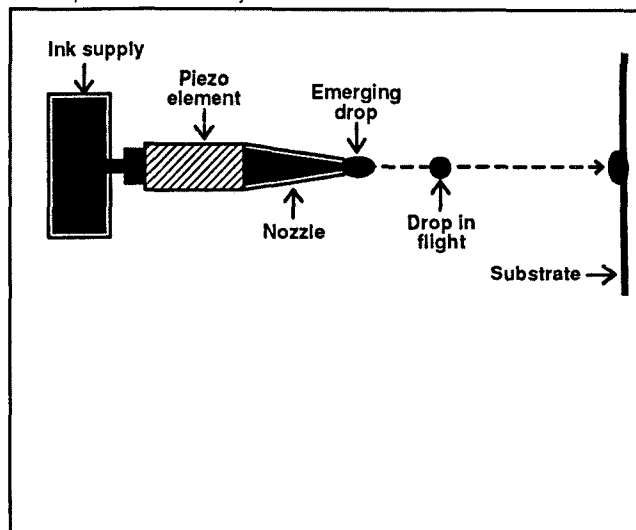
Unlike continuous ink-jet devices, drop-on-demand ink-jet systems eject ink droplets only when required. There is no need to provide for ink recirculation, and in most cases pressurization of the ink stream is not necessary. The basic operation involves generation of a pressure pulse in a pumping chamber to force ink out of a nozzle. Several of these jetting "modules," consisting of a nozzle, ink source, and firing mechanism, are arranged in a pattern to create dot matrix imaging capability. The pressure pulse can be generated in one of three ways, depending on the device.

Valve jet systems use a solenoid-activated valve to control expulsion of ink drops, producing large drops of ink at relatively slow rates. Although a hot-melt valve jet printer has been described (5), such a system has not attained widespread commercial use. A second method for generating the pressure pulse uses heat to produce a vapor bubble in an aqueous ink. As the bubble expands and subsequently breaks within the ink chamber, a droplet of ink is forced out through a nozzle connected to the chamber. This technology is the basis of a number of commercially successful ink-jet printers.

The third jetting mechanism found in drop-on-demand systems employs a piezoelectric transducer to stimulate the ejection of ink droplets, as shown in Fig. 6. When a voltage is applied to the transducer, a dimensional change takes place in the piezoelectric material which is directly coupled to the ink. The resultant pressure pulse is sufficient to squeeze or pump a droplet of ink out of the nozzle toward the target. Jetting frequencies on the order of 10,000 drops/s are typical. Each individual drop weighs on the order of 0.1 micrograms and produces a dot on the substrate 100–200 μm in diameter.

Early drop-on-demand printers, used primarily for office applications printing on paper, employed aqueous or solvent type inks. A major disadvantage of these inks was that the print quality was dependent on the porosity of the paper, so special papers were needed to achieve optimum results. Another disadvantage was that the inks

6. Drop-on-demand ink-jet



would tend to clog the nozzles during idle periods due to evaporation of solvent. Nonvolatile inks, which rely on absorption into a porous substrate as a setting mechanism, have also been used. Although this eliminates the clogging problem, print quality still depends on migration of ink into the substrate. The ability to produce smudge-free prints on nonporous surfaces is also not possible in this case.

The advent of hot-melt drop-on-demand ink-jet eliminated the dependence of print quality on substrate surface properties. The almost instantaneous freezing of the ink droplet on the surface produces stable, consistent, and high-quality prints regardless of the medium on which it is being printed.

The design and function of a hot-melt jetting device places significant demands on the ink. Not only do the chemical, thermal, and rheological properties have to be compatible with the operating parameters of the device, the ink must provide the adhesion, color intensity, and rub and offset resistance required by the application. A number of patents have been issued describing hot-melt ink-jet inks (6–10).

Melt viscosity is perhaps the most critical property of a hot-melt jet ink. To jet properly, the ink viscosity must remain within a narrow range at the operating temperature of the device, typically 100–150°C. At the specific temperature, a viscosity of 10–50 cps is usually required. By most hot-melt adhesive and coating standards, this viscosity requirement is extremely low. The jetting process is also dependent on the surface tension of the ink.

The ink must also demonstrate some degree of thermal stability. It is likely that the ink will be held at operating temperature when printing is not active. Chemical changes due to thermal degradation or volatilization could produce changes in viscosity which would prohibit proper jetting. Also, generation of particulate matter could clog jet nozzles, which are on the order of 50 μm in diameter. The ink has to be chemically compatible with components used in printhead construction.

Once all the operational parameters mentioned above are met, the properties of the ink must satisfy the needs of the particular application. In general, the print must

be resistant to smudging, abrasion, and offsetting. Print quality and the ability to produce color are crucial for the office and graphics markets. In industrial marking applications, where the surface being printed on is usually coated and nonporous, ink durability is of great significance. After being printed, an object may be subject to temperature extremes, high humidity, and chemical exposure. Also, as the object is transported to its final destination, the print may be subjected to abrasive contact with numerous surfaces. Given the formulating constraints imposed by the viscosity limitations of the ink-jet device, this is usually not a trivial task.

Summary

Although the current market for hot melts used in printing applications pales by comparison with the more traditional hot-melt coating and adhesive markets, this area of specialization has significant potential. In addition to environmental considerations, hot-melt inks can provide the high-quality performance demanded by the evolving generation of printing devices. The rapidly growing area of computer-controlled electronic imaging will play a major role in driving the further development of hot-melt printing technologies.□

Literature cited

1. Slaughter, G. T., Evaluation Methods for Business Form Copies, ASTM STP 482, 1971, p. 44.
2. Anderson, S. Jr., "Hot Stamping," Modern Plastics Encyclopedia, McGraw-Hill, New York, 1990, p. 397.
3. Rotheiser, J. I., Plastics Design Forum, p. 41(November/December 1990).
4. Berry, J. M., and Corpron, G. P., U.S. pat. 3,653,932 (1972).
5. Ball, J. M., U.S. pat. 4,684,956 (1987).
6. Merritt, A. R., Cooke, T. M., Lin, A. R., and Whitfield, R. G., U.S. pat. 4,390,369 (1983).
7. Merritt, A. R., Cooke, T. M., Lin, A. R., and Whitfield, R. G., U.S. pat. 4,484,948 (1984).
8. Lin, A. R., and Cooke, T. M., U.S. pat. 4,659,383 (1987).
9. Lin, A. R., Whitfield, R. G., and Cooke, T. M., U.S. pat. 4,758,276, (1988).
10. Nowak, M. T., U.S. pat. 4,820,346 (1989).

The author wishes to thank Richard Larson and Pat Raynes for assistance in preparing this manuscript.

Received for review March 6, 1991.

Accepted Sept. 20, 1991.

Presented at the TAPPI 1991 Hot Melt Symposium.

Keywords: Hot melts, ink, methods, performance, printing, product development, properties, value added products.