An Overview of Applications for Polyurethane Materials in EP Systems

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Abstract

This paper explores the many applications of polyurethane materials, both conductive, and non-conductive, in electro-photographic systems. An overview of general urethane chemistry is provided along with general manufacturing processes for these materials. Specific applications for polyurethane materials in digital printing are explored in detail. These applications would cover charge and developer rollers, cleaning blades, particle transfer rollers, intermediate toner transfer, squeegee rollers, paper transfer, paper and media feed and use of high-density micro-cellular foam rollers for high-speed high reliability feed. In addition, novel uses such as multi-durometer rollers, an-isotropic rollers and highly conductive loaded silicones for EMF shielding are discussed. This paper combines key overview aspects of three papers previously presented at NIP-16, 17 and 18 by this author but also expands on the functional characteristics that make polyurethane the material of choice in the above mentioned applications.

Basic Polyurethane Chemistry

Polyurethane

Any of various synthetic polymers produced by the polymerization of a Polyol or Amine Hydroxyl (OH) radical and Isocyanate (NCO) group from two different compounds.

$$\underset{\text{Isocyanate}}{\text{R-N=C=O}} + \underset{\text{Polyol}}{\text{R'-O-H}} \longrightarrow \underset{\text{Urethane}}{\text{R-}\overset{\overset{\text{H}}{|}}{\text{N}}\text{-}\overset{\overset{\text{O}}{\|}}{\text{C}}\text{-O-R'}}$$

Figure 1. Polyurethane Material formation

The molar ratio of active NCO sites to active OH sites is called the "Stoichiometric Ratio" or "Percent Theory" [inversely the "Index"]. This Ratio is the primary manufacturing control for the formation of the urethane. The Index can be changed and used to adjust product physical properties and, sometimes, electrical properties. Urethanes can be made electrically semi-conductive by formulating with ionic conductive agents. These conductive agents can be liquid or made soluble in urethane cure systems or in the reactive polyol or chain extender components within the urethane chemistry. Since these agents are not "electronic" conductors, flow of current through them depends upon, and is limited by, the nature of the ion, the total number of charge carriers, and the mobility of the ions within the cured urethane system. Mobility is a function of cross-link density of the urethane as well as the structural arrangement of soft segment and hard segment links and the size of the ions of the conductive agent.

EP Applications for Conductive Urethane Materials

Inherently Semi-Conductive Polyurethane rollers and blades are currently being used in EP systems in the following functions:

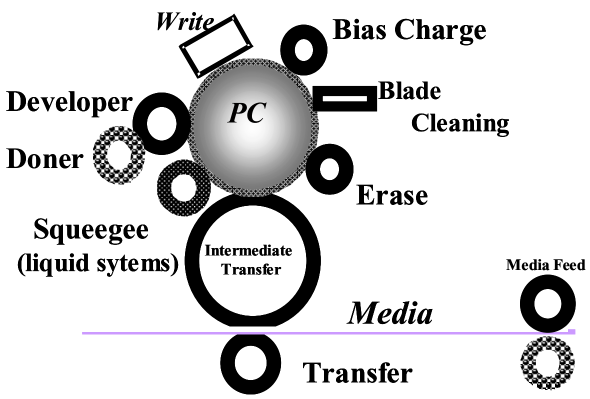

Figure 2. Current EP Applications using Polyurethane Materials

Charge, Donor and Developer, and Squeegee Functions

Starting in EP Process sequence, Ionic conductive Polyurethane is being employed for Bias or Primary Charge Roller (BCR, PCR) function. Typical volume resistivity for this purpose is 10^6 to 10^8 ohm-cm and hardness of Shore-A 25-50. Hardness and conductivity are the most critical parameters for charging rollers. Surface roughness is not as critical for this function, as it is not directly involved in creating or transferring the image. Conformity of the nip, and nip residence time becomes critical in higher speed copier or digital laser printing applications. Abrasion, cut and tear resistance, run-out and bond to the shaft are not as critical due to the low (spring loaded) idling drive against the smooth surface of the OPC in the absence of toner.

Developer rollers typically have a very smooth surface. The "as-cast" molding process is often used for liquid toner developer rollers, and a fine, matte, ground and polished surface is used for dry toner developer rollers. Surface finish, electrical characteristics, freedom from attribute surface defect, chemical resistance (for liquid systems), dimensional tolerances and stability are all critical parameters. The developer roller is by far the most demanding application to specify requirements for within the EP System.

Abrasion resistance can be critical in applications where the developer roller surface speed is different than the OPC surface speed (wiping action) employed often in dry toner applications to impart tribo-charging to the toner particles. For this same reason, surface finish and electrical characteristics (including Resistive-Capacitive charge and decay) are critical. For dry toner systems, a "polished" Developer surface of Ra 0.5, Rz 2.5 – 5.0 often is specified. There exists a relationship between toner particle size and optimal Rz surface finish. Rz is more discriminating than Ra because it takes into account the valley distances and other types of topography such as relatively more widely spaced grind patterns than Ra will show. This is due to the way in which Ra and Rz are calculated. For most EP applications, Rz is better employed than Ra, but current EP industry practice is slow to switch to Rz ONLY. Some companies specify both, but this is sometimes a conflict, especially when urethane is specified instead of conventional rubber. The relationship between Ra and Rz is not constant and is a function of material and machining or casting process.

Developer roller surface finishes for liquid toner systems must be on the order of Ra 0.3 um and Rz 2.0 um. Chemical resistance (esp. to Isopar) is required for liquid toner systems. For this reason, a TDI or MDI Poly-*ESTER* based backbone is typically chosen. Where water based systems are used, Poly-*ETHER* systems are usually chosen. New opportunities exist for water based high-speed conventional printing systems for the use of Polyurethane instead of convention rubber or NBR. New urethane technology also allows Polyester-Polyether blends to address instances where water is a component in a solvent -based system.

The donor roller in dry systems is usually an inexpensive open cell urethane foam, low tolerance, very conformal, and used to "brush" a uniform layer of toner onto the OPC. This layer, in turn, is leveled down to a mono-layer (one to three toner particles high) by an elastomer "doctoring" blade. In liquid systems, donor rollers can be solid urethane elastomer, and would have similar characteristics to the developer roller.

In liquid systems, the squeegee roller is employed to squeeze down the toner particles, laid out by the developer roller, into more intimate contact with the OPC surface and to squeeze out the residual Isopar or toner suspension media in the pre-nip region. This minimizes the amount of liquid solvent transferred to the paper or print media and subsequently out to the fuser system. While the squeegee does not directly hold or transfer the image, it's function is nearly as critical in that it has the opportunity to distort the image as it is squeezing. Dimensional stability, tight tolerances, and uniform surface finishes are required. Electrical characteristics are not as critical and volume resistivity for this function is usually held between $5x10^7$ and $8x10^9$ ohm-cm. Hardness' from Shore A 40 to Shore A 65 are typically called out, and Polyester based backbones or Ester-Ether blends are utilized for solvent resistance.

Intermediate Transfer and Transfer

The next application is increasingly being utilized, and that is the Intermediate Transfer roller or "drum". This function exists to allow the IT drum to be the "sacrificial" surface and extend the life of the OPC. It also allows for conformance of the image-carrying surface to differing media surface textures and thickness. Conventional OPC drums are typically made from hard, non-conforming, low abrasion resistant materials. This is increasingly important as the world of digital imaging moves into markets previously dominated by high-speed offset lithography.

By utilizing conductive polyurethane in the IT function, the OEM also decreases the "Total Cost Of Ownership" of the EP printer by making a less expensive part sacrificial, and in a location which is easier to service and replace.

The IT drum is typically the same diameter as the OPC, and is a medium durometer (50-70 Shore A), conductive (10^6 to 10^{8or9}) medium wall thickness (5-20 mm) drum. Very tight dimensional and surface finish tolerances are required and precision grinding and polishing are often employed to manufacture these drums. Straightness and cylindrical runout are critical as is diameter and surface (both roughness and the surface energy related to transfer and toner retention after transfer). The IT Drum is sometimes coated with a low surface energy, very thin, smooth conformal coating to aid in image transfer and toner release. The surface, having a direct image carrying function, must also be free from attribute defects. As such, very clean environments are required during final finishing operations and coating (similar to OPC manufacture). Material properties of hardness, compression set, and resilience are as critical as dimensional characteristics in the IT application, and should be carefully specified.

The Transfer Roller (or sometimes referred to as the Paper Transfer Roller) can function simply to provide transfer bias to the media, or can also feed the media. The surface finish of this roller is not as critical as the others, but must have some grip to it for proper feeding. Dimensional tolerances are typically tight (0.05 mm cylindricity or greater), but not ultra-precision. Volume resistivity is normally in the range of 5×10^8 to 3×10^9 ohm-cm with a hardness of around 50-65 Shore A.

Paper and Media Feeding Rollers and Tires

Media feed or paper feed rollers and tires can be made from solid elastomer or high-density self-cleaning polyurethane foam. The nature of a high-density closed cell foam allows for the feed roll or tire to clean itself during use. The repeated compression cycle of going through the nip flexes the surface of the urethane and literally slings buildup of clay coatings and paper dust off the surface of the roller. This provides unique advantages compared to solid elastomer surfaces in that no glazing and hardening of the surface will occur. Use of this type of media feed system has been shown to allow for over 2,000,000 sheet feeds without failure. Coefficient of friction as well as "traction" and conformance of the surface of the roller to the paper surface are important characteristics. Feed rollers and tires typically range in hardness from 25 to 40 Shore A. Surface finishes for this function vary widely, but typically, the smoother the better for traction. Media feed rollers can be made the entire paper width, but are more often in the form of single wheels or tires of 15 to 30 mm wide located in two or three locations across the paper width. Some systems employ multiple feed roller functions with separate nudging, feeding and retarding rolls and complex clutch systems. Other systems utilize more simple spring loaded feed wheels against a solid idler wheel. Still others use thin metal feed cogs that impart a slight perforation to the media. The cogs roll against a solid urethane tire and the media is fed through the nip. This is typical of very low-end printers.

Multiple Layer Rollers and Coated Rollers

There are a variety of constructions of multiple layer and multiple hardness rollers that can be manufactured using liquid cast urethanes that cannot be manufactured with other molding technologies such as compression molding. These constructions include multiple layers lengthwise, multiple segments of different hardness and hard end caps with soft urethane in the middle and additionally thin Teflon sleeved soft polyurethane allowing for a low C.O.F. and high release surface with the conformance of a soft layer underneath. These rollers exhibit anistropic behavior being stiff axially and in the rotational direction, but soft in the radial direction. This technology is being employed in capstan rollers for dye sublimation kiosk printers. Other options would include thin film release coated polyurethane as well as powder coating for release from media such as Mylar film and transparencies or to prevent adhesion or damage to OPC surfaces.

Silicone Rollers

Silicones are also being employed successfully in film feeding applications as well as imaging applications requiring heat transfer or heat resistance. There are a variety of thermally and electrically conductive silicones on the market that are both soft and tough as well as being able to withstand higher temperatures. Thermally conductive Silicone is widely used in the fuser roller application as well as heat transfer for development for dry photographic and X-ray film technology. Electrically conductive silicone and silicone foams are gaining further R&D placements for charging OPC surface due to the fact that silicone will not contaminate or react with most organic OPC coating chemistries. Electrically conductive silicones have some limitations with respect to being very conductive, typically in the 10^1 or 10^2 ohm-cm range, as opposed to semi-conductive. This often requires some type of electrically insulating sleeve or coating over the surface. This is being done for OPC charging with failure modes often being pinholes in the coating resulting in arcing and damage to the OPC. A number of silicone suppliers are currently addressing these limitations and are offering some semi-conductive formulas. Processing of these chemistries can be difficult however due to their inherently high viscosity. These silicones tend to be paste-like in the un-reacted state and are difficult to pump and de-gas and require high-pressure injection molding or L.I.M. technology. This comes at a premium requiring fairly large capital investment. As a result, R&D in this area has been slow.

Conductive Silicone as RF-EMI Shielding

Another potential area of use for highly conductive silicone is that of RF and EMI shielding. This class of silicone is usually "silver coated glass bead" highly loaded silicone resin. Grommets and gaskets can be molded out of these materials without the need to punch these small shields out of metal. Also, this material can be molded directly to connectors or other metal frame components allowing for flexible fit of shielding around devices and connections. This allows the manufacturer to use a wide dimensional tolerance on the shielding gasket or grommet, and even in assembly tolerances, which is an advantage over hard or rigid metal shields that would require tighter dimensional tolerance control. This use has grown in recent years due to greater regulatory pressures both in the EU and USA regarding RF and EMI emitting devices, especially as processor speeds are now in the GHz range.

Biography

Charles Matteliano is currently Vice President of Product Development and Quality for Winfield Industries, Inc., Buffalo, NY, USA. His responsibilities include directing materials, process and product development activities for polyurethane and silicone engineered components including imaging, film and EP process rollers. Charles holds a Graduate Degree in Applied Math and Statistics from RIT, and a Bachelors Degree in Industrial Technology from SUNY. Past experience includes Quality/Materials Manager with BIC SMD, Clearwater FL; Supervisor for Westinghouse Electrical Controls Division, Oldsmar, FL; Quality/Process Development Engineer with Buffalo China, Inc.; and Quality Manager at Winfield Industries, Inc., www.winfield-inds.com