

# Effect of medium (substrate) on toner adhesion

Suresh Ahuja, Physicist. 1192 Gatestone Circle, Webster, NY 14580

## Abstract

Adhesion of toner to a medium such as paper or plastic depends on modulus of toner paper interface that is energetic of interactions and dynamics. Energetic of interactions depend on spontaneous spreading of high surface tension liquids, while interfacial dynamics is controlled by surface friction.

Surface energy is reviewed for toner and medium used in making images. Adhesion of two different solid surfaces can be predicted from their ability to induce spontaneous spreading of high surface tension liquids because interfacial forces govern the processes. The friction behavior of solid surfaces, on the other hand, is controlled by the interfacial dynamics, which has some features that are common to the sliding behavior of a liquid drop on a solid surface. In the absence hysteresis, surface energy by contact method is comparable to the indirect method by wetting. The adhesion is analyzed in terms of wetting and drop spreading. While wetting is dependent on surface energy of toner and medium, toner spreading is influenced by the ratio of surface energy to viscosity of the toner.

## Introduction

The entanglement between the two materials controls the adhesion between two different non-reacting polymers such as between toner and paper or plastic[1]. If the materials are essentially insoluble in each other and the interface between them is very narrow, low adhesion can be expected. Adhesion of toner to paper or plastic depends on wetting and spreading of heated toner. Surface chemistry and surface forces such as van der Waals or electrostatic forces are essential for determining wetting of a fluid to a given surface. In addition a heated toner spreads and this involves moving contact line at the edge of a spreading molten toner resulting from both large scale (hydrodynamic) forces and short scale (molecular) dynamics. If we consider a liquid drop on a solid substrate, there are three different phases present. Young's equation [2] gives the relation between the equilibrium contact angle  $\theta_{eq}$  the drop makes with the surface and the three surface tensions as

$$\gamma_{SV} = \gamma_{SL} + \gamma \cos \theta_{eq} \quad (1)$$

If  $\gamma_{SV} < \gamma_{SL} + \gamma$ , a droplet with a finite contact angle minimizes the free energy of the system; partial wetting takes place. if  $\gamma_{SV} = \gamma_{SL} + \gamma$ , the contact angle is zero. The system

Is in equilibrium when a macroscopic uniform liquid layer covers the whole solid surface and complete wetting takes place.

After de Gennes,[3]: spreading coefficient is given

$$S_i = \gamma_{SO} - (\gamma_{SL} + \gamma) \quad (2)$$

where  $\gamma \equiv \gamma_{LV}$  denotes the liquid vapor surface tension  $\gamma, \gamma_{SO}$  is the surface tension of the dry solid substrate. For non-volatile liquids and  $S_i > 0$  the droplet will flatten as it attempts to spread, while preserving its volume. The distinction between the different wetting states is usually made by considering the equilibrium spreading coefficient  $S_{eq} = 0$ , which represents the surface free energy  $\gamma_{SV}$  relative to its value for complete wetting. Zisman [4] found that the difference  $\gamma_{SV} - \gamma_{SL}$  is a property of the solid, i.e., a constant independent of the liquid used. Using a liquid with a known liquid-vapor tension, this difference can readily be evaluated by measuring the contact angle of that liquid on the solid substrate, and using (1). The constant is the intercept of a straight line through the data with the horizontal  $\cos \theta_{eq} = 1$ , which motivates the name "critical surface tension" for  $\gamma_{SV} - \gamma_{SL}$ . Rearrangement of equation leads to straight-line plots of  $1/\cos \theta_{eq}$  and  $\gamma_{LV}$  with extrapolation passes through the origin. Critical surface tension of has been analyzed for polymers with a wide variety of liquids using Zisman plots.. Table below gives different surface energies depending on the chemical structure of the surface. Fluorinated polymers give low surface energy while polyvinylidene gives highest surface energy.

The critical surface tension of wetting is equal to the surface free energy of a solid only when the interaction parameter  $\phi$  is equal to unity. A frictional interface at rest becomes stronger as time lapses: it strengthens when aging. When sliding, it becomes

Table 1  
Critical surface tension of wetting and surface composition

Polymer	Structural formula	$\gamma_c$ (mJ m <sup>-2</sup> )
Poly(vinylidene chloride)	$-(CH_2CCl_2)_n-$	40
Poly(vinyl chloride)	$-(CH_2CHCl)_n-$	39
Polyethylene	$-(CH_2)_n-$	31
Poly(vinyl fluoride)	$-(CH_2CHF)_n-$	28
Poly(vinylidene fluoride)	$-(CH_2CF_2)_n-$	25
Polytrifluoroethylene	$-(CF_2CHF)_n-$	22
Polytetrafluoroethylene	$-(CF_2)_n-$	18
-CH <sub>3</sub> (crystal)	-CH <sub>3</sub>	22
-CH <sub>3</sub> (monolayer)	-CH <sub>3</sub>	24
-CF <sub>3</sub> (monolayer)	-CF <sub>3</sub>	6
Polystyrene	$-(CH_2CHC_6H_5)_n-$	33
Poly(methyl methacrylate)	$-(CH_2CH_2COOCCCH_3)_n-$	39

weaker: it can be said to rejuvenate upon sliding. Moreover, its dynamic age in steady motion decreases with increasing velocity. Depending on contact pressure a frictional interface is a jammed junction or an adhesive junction..

In adhesion of toner to a medium such as paper or plastic, spreading of a viscous drop follows wetting to the surface. Spreading of a viscous drop has been analyzed when the ratio of viscous to surface tension forces (Capillary number) is small. Drop radius  $R(t)$  spreads as function of time (t) given by "Tanner's law"[5]

$$R(t) \approx \left[ \frac{10\gamma}{9B\eta} \left( \frac{4V}{\pi} \right)^3 t \right]^{1/10} \propto t^n \quad \text{-----(3)}$$

where  $\gamma, \eta, V$  and  $B$  are surface tension of viscous toner, viscosity, volume of the toner and  $B$  constant, respectively.

A direct method of estimating adhesion and surface free energy is based on contact mechanics, which measures the deformation produced on contacting elastic particles under the influence of surface forces and external forces. Since the balance of the elastic and surface forces of the system describes the equilibrium, the load-deformation data can be translated directly to estimate the adhesion and surface free energies. In most cases however, the contact deformations obtained from the loading and unloading cycles exhibit Hysteresis, which are sensitive to the structure and chemical compositions of the interfaces.

## Method and Materials

Critical surface energy for toners and medium (paper substrate) were determined by Zisman method. This method involves measuring angle of contact by putting liquid drops on the toner or paper surfaces. The toner discs for surface energy were produced after molding powders under compression at 60C above  $T_g$ . Both polar and non-polar liquids with different surface tensions were used. When the cosine of the contact angles of the liquids is plotted against their surface tensions, a nearly linear plot is obtained. This line, when extrapolated to the  $\cos 0 \rightarrow 1$  axis, meets the axis at a point which was termed by Zisman as the critical surface tension of wetting " $\gamma_c$ ".  $\gamma_c$  is a measure of the surface free energy of the solid, which demarcates those liquids ( $\gamma_{lv} < \gamma_c$ ) which spread on the solid surface as a thin continuous film from those ( $\gamma_{lv} > \gamma_c$ ) which do not. Zisman found that  $\gamma_c$  varies systematically with the chemical constitution of the solid substrate (1). Toner adhesion to a medium paper or plastic is commonly evaluated by tape test, taber abrader or by crease test. Tape test involves pulling image using a tape and the pulled area is measures for image density compared with the unpulled area. Taber abrasion test uses a taber abrader to abrade image area and the image density of the abrade area is compared to un-abraded area. In crease test, an image area is subjected to rolling force and the image subjected to rolling force is folded /creased Image subjected to rolling contact and flexural force is measured for density and compared to an image which is not subjected to these

forces. Crease test is more applicable to coated papers containing glossy images. In our evaluation of toner adhesion, image fix by crease test was used comparing coated papers and toners with different surface energies.

## Result and Discussion

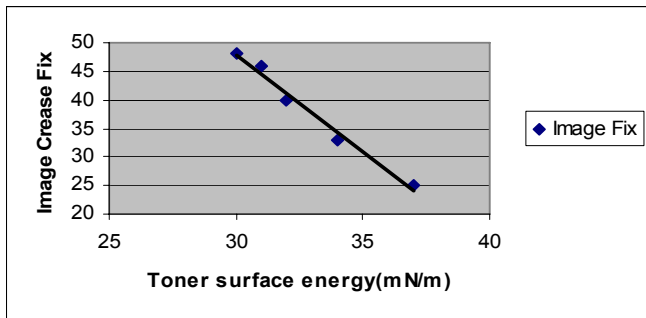
Rough and smooth papers were tested by Sipi for toner adhesion and it was found that smooth surface had better toner adhesion[6]. Most solid surfaces are not homogeneous; dust particles, roughness and chemical heterogeneity may cause thespreading coefficient  $S$  to become dependent on the position on the substrate. For rough or patterned surfaces, minimization of the free energy leads to an equilibrium effective contact angle  $\theta_w$ , that accounts for the extra area of the drop that is in contact with the solid.

$$\cos \theta_w = r \cos \theta_{eq} \quad \text{----- (4)}$$

$\theta_w$  is the effective contact angle and  $r$  is the ratio of the real to the projected area covered by the drop. Roughness ( $r > 1$ ) reinforces the wetting properties of the smooth substrate, in agreement with experiments [ 7]. Work of Pettersson and Fogden on toner spreading showed that surface energy of toner and substrate are important variables which determine optical parameters of dot grain and gloss as well as print adhesion. The prints were analyzed by interferometric profilometer to quantify response of toner layer thickness and surface topography (surface roughness) to the fusing conditions. With high surface energy substrate, toner spreading was significantly higher [8].

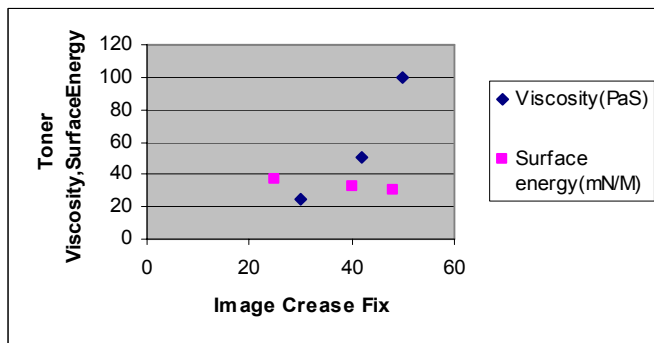
Digital printing is increasingly being used for package printing. One of the major techniques of digital printing is dry-toner electro-photography. The paper evaluates the printability of three different extrusion coatings used for packaging boards: low-density polyethylene (PE-LD). ethylene methyl acrylate (E/MA) and polyethylene terephthalate (PET). Extrusion coatings in general have an impervious, chemically inert, nonporous surface with low surface energies that cause them to be non-receptive to bonding with toners. The most common methods used in improving the adhesion properties of polymer coatings are different surface treatments. These increase the surface energy and also provide the polar molecular groups necessary for good bonds between the toner and polymer molecules. The polymer coatings have been modified with electrical corona discharge treatment. The effects of corona on polymer surfaces and the correlation between surface modification and print quality have been evaluated. Results show that sufficiently high surface energy and surface-charge uniformity are necessary for even print quality and toner adhesion. E/MA and PET have the required surface-energy level without the corona treatment, but PE-LD needs surface modification in order to succeed in the electro-photographic process. E/MA also has exceptional surface-charge properties compared with PET and PE-LD [9].

Toners with different surface energy were selected. The toners were fused on a coated paper. Crease fix was measured. Results showed correlation between crease fix and toner surface energy. Toner adhesion increases as image fix decreases.



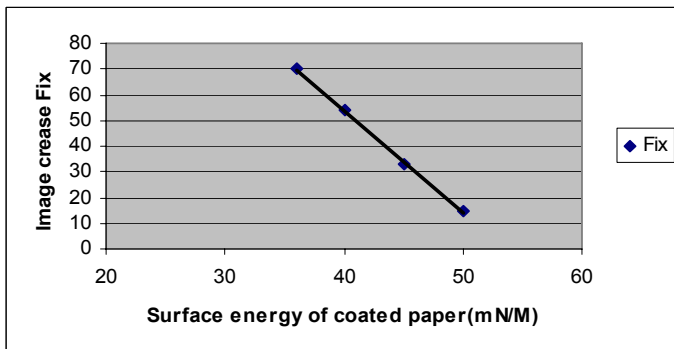
**Figure 1 is a plot image crease Fix and toner surface energy**

When viscosity of toners is varying dramatically compared with surface energy, image crease fix becomes more dependent on viscosity because of higher spreading of molten toner. An illustration is given in Figure 2.



**Figure 2 is a plot of viscosity, surface energy and image crease fix**

Coated papers were selected which differed in surface energy. They were used as substrate and toner was fused. Image fix was measured by crease method. A correlation was obtained between crease fix and paper surface energy.



**Figure 3 is a plot of image crease fix and surface energy of coated paper**

## Conclusion

Toner adhesion to a medium paper or plastic is dependent on wetting of molten toner to the medium and spreading of the molten toner. Wetting of toner is analyzed to be dependent on the surface energy of the toner and the medium. Spreading of the molten toner follows Tanner's law and is dependent on the ratio of surface energy to viscosity. If surface energy of a medium were constant, toner viscosity rather than toner surface energy would normally dominate.

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## Author Biography

*Suresh Ahuja received his BS in physics and chemistry from the Punjab University (1959), his MS in Soil Physics from Indian Research Institute (1961) and his PhD in Polymer Physics from Polytechnic Institute of Brooklyn (1967). After working over 37 years at Xerox with several years as Principal Scientist he retired. He has over twenty(20) patents.. He has published over 50 publications and presentations at international conferences. He is a member of APS, ASME, SOR and IST.*