Contact and Non-Contact Fusing and Fixing of Toners

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Abstract

Demand on material properties of toner especially viscosity and elasticity are different depending on whether fusing is accomplished by contact or non-contact means. In roll fusing (contact fusing) toner particles are subjected to pressure and heat for dwell time dependent on the roll speed and nip length. The assembly of toner particles goes through compression while the layer is being heated. The molten particles are subjected to shear which results in changes in viscosity and elasticity. Subsequently as the toner particles on the media separate from the roller, they go through stretching at fairly high rates depending on the speed of the roller. Difficulties arise when heat is applied to the media, which leads over drying of the media and causes difficulties in media handling. The pressure distribution can cause image deformation and media curling. In non-contact fusing, radiant fusing, flash fusing, microwave fusing or steam fusing, toner assembly is subjected to intense heat without external shearing or stretching. Coalescence and spreading of the toner particles take place quickly and efficiently. Adhesion of toner to the media is expected to be stronger. Non-contact fusing is contrasted with contact fusing models and compared with experiments.

Introduction

In a two component developer system, toner is developed on photoreceptor, transferred to media and toner is fused either through the application of thermal energy from a roller, contact fusing or by flash, radiant, microwave energy. In contact fusing and fixing an array of toner particles are either subjected to pressure alone at ambient temperature conditions or to both pressure and temperature. When pressure alone is applied at ambient conditions to facilitate adhesion and fixing of toner to a medium, it is termed cold fixing of toner. A toner to be selected for cold pressure fixing flattens on application of force and invariably yields resulting in improved adhesion to a medium. The medium is fed through a set of steel rollers. The rollers may be skewed in order to apply the pressure uniformly. Rolling contact on visco-elastic layer has been investigated for decades [1]. Toner particles when subjected to deformation behave elastically or in an elastic-plastic manner depending on flexibility of the macromolecule particle size, molecular weight and rate of deformation [2]. Critical stresses of brittle and ductile particles can be analyzed using Hertzian elastic model and its predictions can be compared with experiments on single toner particles and their compression molded aggregates [3]. Composite modulus and yield stress of toners were analyzed by using law of mixtures and compatibility between the two components making up the composites [4]. Adhesion of particles such as toner particles to surface of a medium can be modeled by JKR and DMT models. In 1971, Johnson, Kendall and Roberts (JKR) [5] proposed a new theory that accounted for adhesion between two elastic bodies. They were motivated by experimentally measured contact areas that were larger than predicted by the Hertz theory at low loads, and by the observation of finite contact area at zero applied load. This minimum load can be called the pull-off force or critical load Pc, and is given by:

$$P_{c(\mathrm{JKR})} = -\frac{3}{2}\pi\gamma R. \qquad (1)$$

where γ is the Dupré energy of adhesion, or work of adhesion When surface forces are short range compared to the resulting elastic deformations (i.e. compliant materials, large sphere radii, and strong, short-range adhesion forces), the JKR model describes the contact area accurately.

Derjaguin, Muller and Toporov (DMT) [6] derived a separate expression to include adhesion in the contact of elastic bodies. They assumed that the deformed contact profile remained the same as in the Hertz theory, but with an overall higher load due to adhesion. The pull-off force is given by

$$P_{c(\mathrm{DMT})} = -2\pi\gamma R. \qquad (2)$$

The opposite limit (i.e. stiff materials, small sphere radii and weak, long-range adhesion forces) corresponds to the DMT regime.

It is convenient to utilize a non-dimensional physical parameter to quantify these limits and the cases in between. Often referred to as Tabor's parameter μ_T, this transition parameter is defined as

$$\mu_T = \left(\frac{16R\gamma^2}{9K^2 z_0^3}\right)^{1/3}. \qquad (3)$$

where z_0 is the equilibrium separation of the surfaces. The spatial range of the adhesion forces is assumed to scale with z_0, as in the case of the Lennard–Jones potential, for example, where z_0 is the only length scale in the definition of the potential. Tabor's parameter is physically equivalent to the ratio between the normal elastic deformation caused by adhesion (i.e. in the absence of applied load) and the spatial range of the adhesion forces themselves[7].

In fusion of toner particles under temperature and pressure, toner-medium(paper) interface temperature is in the neighborhood of 120C and shear rates are in the vicinity of 1000Sec-1 The toner particles undergo coalescence and spreading. The size of the primary particles and the growth of agglomerates are determined by the rate of collision and subsequent coalescence. Qualitatively, at sufficiently high temperature, particles coalesce faster than they collide, and collisions of particles will result in a spherical large particle. However, at lower temperature, particle coalescence is negligibly slow, and a collection of smaller attached particles (aggregates) is produced. The linear rate law for decrease in the surface area was developed by

Koch and Friedlander [10]as

$$\frac{\mathrm{d}a}{\mathrm{d}t} = -\frac{1}{\tau_f}(a - a_{sph}), \tag{4}$$

where a is surface area of particles, a_{sph} is surface area of sphere of same volume, and τ_f is characteristic

coalescence time. The characteristic coalescence time calculated from a solid-state diffusion model.

$$\tau_f = \frac{3kT_pN}{64\pi\sigma D}, \tag{5}$$

where T_p is the particle temperature, N is the number of atoms in the particle, D is the diffusion coefficient reported as an Arrhenius function of the temperature, and σ is the surface tension. For droplets of equivalent sizes, the coalescence time is given by

$$\tau_f = \frac{\eta d_p}{\sigma} \tag{6}$$

where d_p is the diameter of the particle, η is the temperature dependent viscosity.and σ is the surface tension. The above equations provide a reasonable quantitative description of small particles coalescence [11]

Under typical flash fusing, top surface of the toner is subjected to considerably higher temperatures than the melt temperature of the toner [12]. Compared to roll fusing, a contact fusing, flash fusing a non-contact fusing process, the toner temperature is in the neighborhood of 160C compared to 120C in roll fusing. Viscosity of the toner is in the 30-70 PaS in flash fusing fix compared 1000-10,000PaS in toner temperature in roll fusing. Lower viscosity in flash fusing allows faster coalescence than in roll fusing. .

Method and Materials

Viscosity and relaxation modulus of polyester and styrene butadiene toners were characterized by compression molding them and shearing them dynamically in an Ares rheometer [8].

Result and Discussion

The elastic and viscous modulus at various frequencies were subjected to inverse Fourier Transform or numerical approximations to get relaxation modulus as function of time.

Figure 1 data can be clearly used to show that as the molecular weight is decreased, relaxation modulus rapidly decreases with time. The slope of relaxation modulus with time can be used to get relaxation time. If the relaxation time is lower than the process time (dwell time), fusing is less dependent on elasticity of a toner. On the other hand if relaxation time is greater than the dwell time, elasticity plays a significant role and slows down coalescence time.

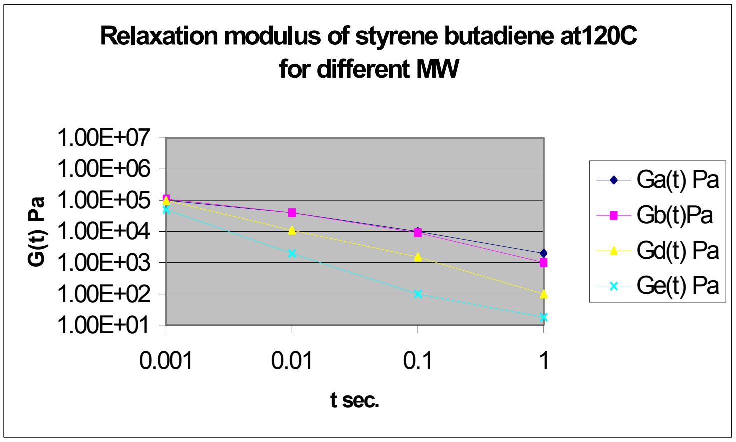

Figure 1 shows that relaxation modulus increases with increase in molecular weight from a to b to c and to d.

Binder styrene butadiene copolymer shows viscosity dependence on molecular weight linearly below entanglement molecular weight and power law dependence above entanglement molecular weight.

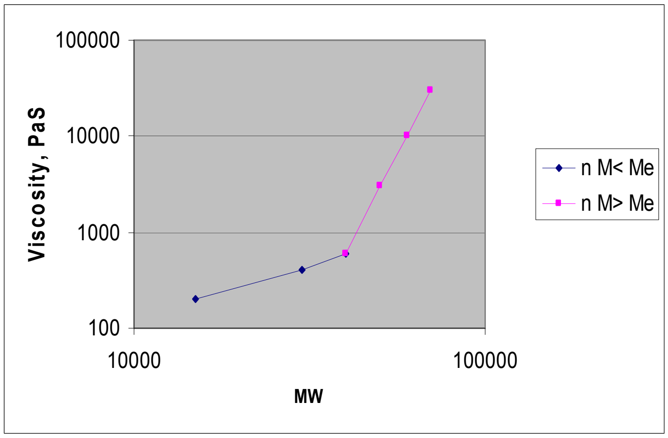

Figure 2 shows molecular weight dependence on viscosity in, styrene butadiene $\eta \propto M$ *for* $M < Me$*,* $\eta \propto M^n$ *nth power of* M

Polymer chains get entangled above a certain molecular weight. Entanglement molecular weight for polystyrene is in the neighborhood of 30K and in the neighborhood of 15K for polybutadiene. Viscosity molecular weight dependence in Figure 2 is consistent with the expected entanglement molecular weight for styrene butadiene. Higher entanglements lead to higher viscosity and lower adhesion to the medium.

There is a threshold in molecular weight below which cohesive strength of the toner image is low and breakable. Both molecular weight and cross-linking have significant affect on cross-linking. Figure 3 below shows that the slope of viscosity temperature flattens on increasing molecular weight in linear polyesters from 30K to 50K. However, largest change in viscosity temperature dependence occurs when polyester is Crosslinked.

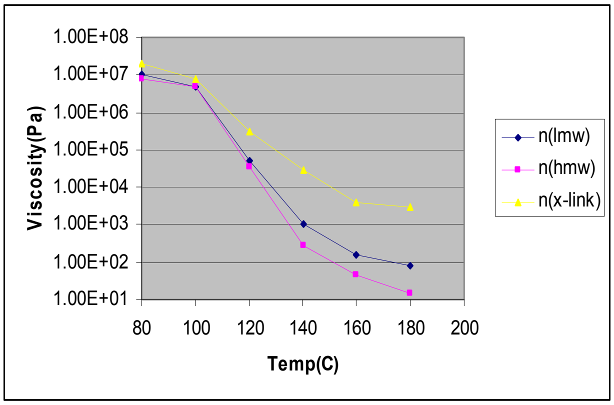

Figure 3- Viscosity dependence on temperature of polyester at 100Sec-1, lmw-30K, hmw-50K, x-link 30% gel

Conclusion

Contact and non-contact fusing involves coalescence and adhesion of toner particles with dependence on processing, material and geometrical parameters. In roll fusing, a contact fusing process, toner paper interface temperature is significantly lower 40C compared to toner in flash fusing which leads to lower coalescence and adhesion (fix).

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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 60 publications and presentations at international conferences. He is a member of APS, ASME, SOR and IST.