Particle Shape of Toners and the Advantage of Using Chemical Toner Manufacturing Methods

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Why is particle shape so important?

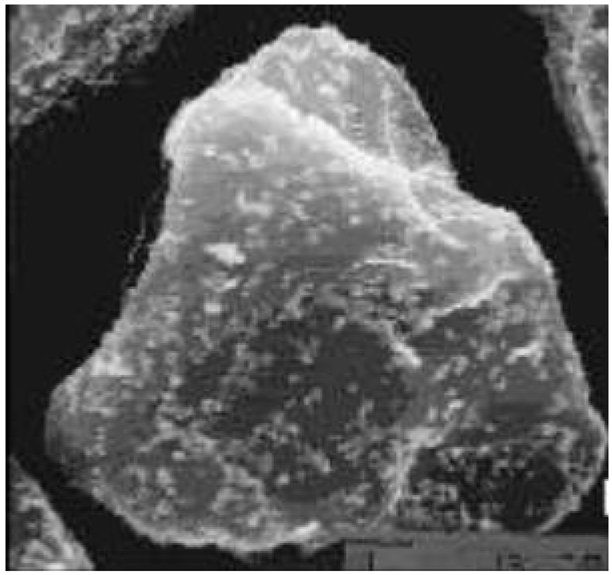
A great deal of R&D effort has gone into improving printer design. The goal has been to produce simpler and increasingly more accurate toner based printer systems with fewer components and improved imaging, which are suitable for a wide range of consumer and industrial digital printing applications. There are many factors and machine parameters that can compromise the final image quality and this can include the toner itself. In order to produce high quality electrophotographic images, it is necessary to carefully control the forces acting on the toner particles. These forces are predominantly either electrostatic or electrodynamic in nature and are affected by toner particle shape.

Toner companies have therefore been faced with the task of improving the toner particles. While individual manufacturers have their own formulae for toners, most comprise around 90% thermo-plastics that are colored with up to 10% of pigment and fixed with heat after transfer to paper. Traditionally, dry toner particles are made by compounding, followed by fine grinding, classification and blending. The resulting fine powder has a tight specification for particle size distribution consistent with commercially economical production. The conventional method of toner production has several drawbacks, notably variation in particle shape and charge-to-mass ratio. Non-uniformity in these, as well as other toner properties, can cause problems during the steps involved in the print process. Particle shape has a fundamental affect on toner properties including transfer efficiency, developability, and cleanability.

The ability to control and affect the predictability of the effects of electrostatic and electrodynamic forces in the image creation process lies with the way in which the toner is prepared. The method and conditions of preparation affect the shape, size, size distribution, mean charge and charge distribution of the resulting toner. The trend and requirement in toner technology is to increase homogeneity, make uniform and smaller toners with narrower particle size and charge distribution. These requirements are from the need and desire for the production of higher resolution images from today's and tomorrows toner based printers. The ability to achieve shape control, narrower particle size distribution and narrower particle charge distribution by improved homogeneity of composition is significant. Mono-component Development has become increasingly popular as a development technology in print engines. Compared to two-component development, toner particle shape plays a relatively more important role in Mono-component Development. Toner manufacturers have looked to chemically prepared toner methods to solve the problem of manufacturing uniformly shaped and sized homogenous toners.

Toner Shape Characteristics

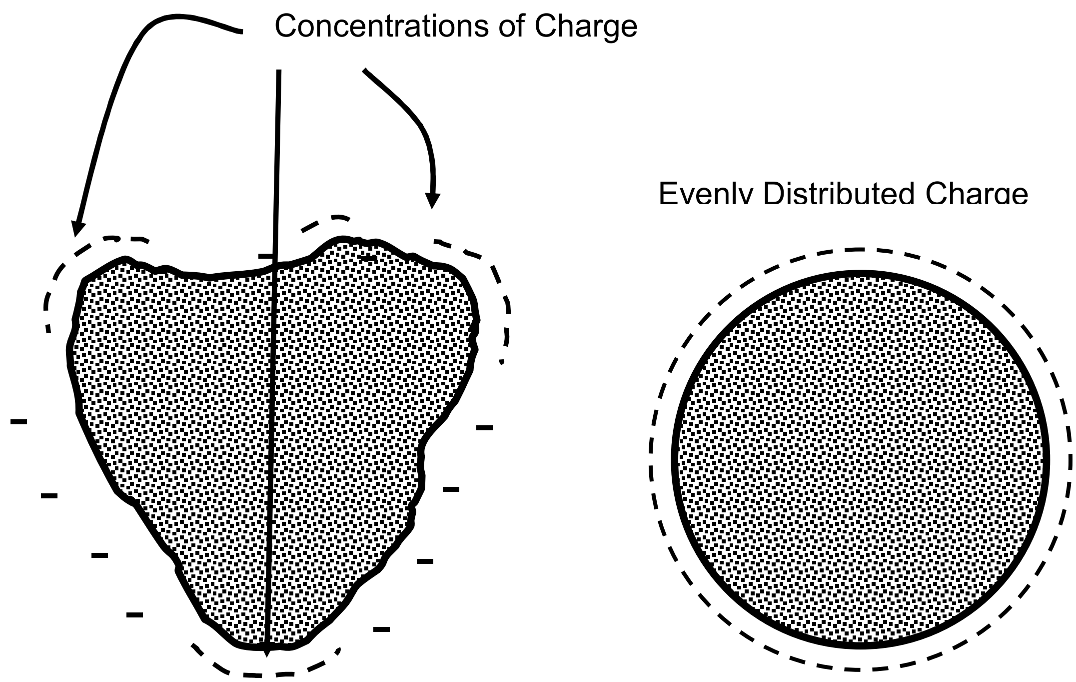
Until recently the prevalent method of toner production has been the so called conventional method in which the toner particles shape is determined by the method of size reduction used, typically mechanical or jet milling. These methods characteristically produce rough granular shaped toner particles. A Scanning Electron Micrograph (SEM) of a typical toner produced by this method is shown below.



Physicists have long sought to predict and describe the mechanisms and performance of toner particles in development systems. The models they have developed of the mechanisms have relied upon several assumptions including that toner particles can be treated as essentially spherical objects. Regular shapes such as spheres, because of their regularity of shape, behave electrically and mechanically in predictable ways. With this assumption, it is possible to readily use mathematical methods to calculate and predict performance. At he same time as the physicists wanted to impose upon conventional toners, the chemists and toner formulators have wanted to create in the modern day toner for use in high quality print engines that gives the physicists what they want. This predictability and uniformity of behavior is not a feature of conventionally manufactured toners that are in fact non-spherical, non-uniform and are imperfect in homogeneity.

Electrostatic Performance of Different Shaped Particles

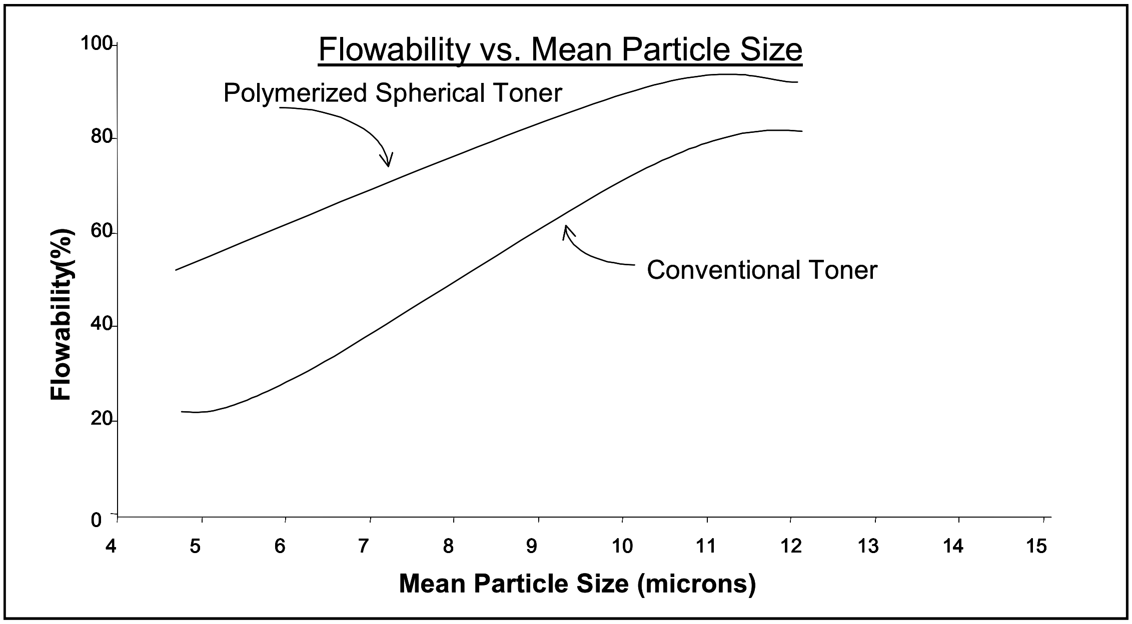
Much of the performance dynamics in toner-based printing is influenced by electrical and electrostatic properties of the systems in the print engine including the toner. In high quality toner based print systems it is very important that toner behaves in a uniform fashion particle to particle. Uniformity is created in toner by virtue of a high degree of homogeneity in composition within individual particles as well as when comparing particles. The closer toners are in uniformity of composition and shape the more uniformly the toner will perform and the better the quality of print performance will be. This uniformity enables, amongst other things, even tribo-electric charging of toners, both in charge to mass ratio particle to particle and also even distribution of charge on each particle' surface. The most regular and uniform of rounded three dimensional particle shapes is the sphere. The electrostatic charge distribution of a charged sphere compared to an irregular shape is illustrated in the diagram below.



The charge on the surface of any object tends to be concentrated at the areas of maximum curvature. Thus on the irregular toner particle on the left, the toners' charge is concentrated at the points, projections and sharp areas of the shape creating localized "hot spots". On the spherical toner particle the toner charge is distributed evenly over the whole surface of the toner. Remembering that the whole mass of a conventional toner is comprised of irregular and dissimilar shapes, this means that each particle differs in its behavior under the influence of electrostatic fields used in the development step. This randomness leads to unpredictable and irregular development particle to particle that degrades image quality. By comparison, the evenness of charge behavior of the spherical toner leads to a toner that with all other factors equal gives better print quality.

<u>Flow Performance of Different Shaped Particles</u>

In most Mono-component Development processes the toner resides on the developer roll after doctoring in a very thin layer. The evenness and consistency of this layer are significantly impacted by such major factors as toner flow. The flowability of spherical or rounded shape toner particles is significantly better than angular granular types. The graph below plots the change in flow with change in toner particle size for both conventionally prepared toner and spherical suspension polymerized toners. These represent the extremes of the shape envelope and rounded rather than spherical toners would be charted somewhere in between these two extremes.



In addition to the ability to enable better flowing toners by producing toner particles with more rounded shapes, the ability to minimize the quantity of flow promoting surface additives helps to make a more uniform and robust toner. The lack of surface additives can translate into homogeneous electrostatic charge behavior that leads to minimization of performance defects and limitations.

The ability to control particle homogeneity within a toner particle and from toner particle to toner particle enables the achievement of narrower particle charge distribution and thereby helps to achieve better print quality.

It would seem that the ideal shape toner particle would be a spherical toner particle. However, there are other requirements of toners that are adversely affected by rounded shape. Blade cleaning is the method of choice for photoconductor cleaning in toner-based printers. The efficiency of the blade cleaning system is dependent upon an appropriately high coefficient of friction at the blade/drum interface. This interface can be a blade/toner/drum interface. Rounded toner particles tend to roll easily compared to irregularly shaped particles and reduce the frictional force at that point. This reduces the efficiency of the cleaning process. Some early print engines which used spherical suspension polymerized toners had so called cleanerless architecture which was as much for the reason that the transfer efficiency was claimed to be near perfect, as that blade cleaning was inefficient.

Toner Adhesion

In the printing process toner is charged in contact with the development roller/magnetic roller sleeve and adheres to that roller by electrostatic and/or magnetic attraction. Additionally, like any other finely divided powder, toner adheres to surfaces that it contacts by forces other than electrostatic attraction. This component of adhesion forces is the result of close proximity forces often described as Van der Waals force.

The electrostatic forces acting on toner particles in the development zone of the print engine are complex and many. They are summarized as follows:

- coulombic repulsion between the charged toner particles
- attractive and repulsive forces (discharged area development) between the electrostatically charged photoconductor and the charged toner particles
- attractive (charged area development) force between the toner particles and an electrostatic image charge in the conductive layer of the photoconductor
- force generated by the development bias electrostatic field and the charged toner particles
- attractive force between the toner particles and the development station, which can be coulombic, magnetic or both

For optimum performance these forces must be controlled and toner performance be made predictable. In addition to these applied forces there are other forces that affect the toner particles. These are electrodynamic forces. These forces tend to manifest themselves as Van der Waals interactions and predominantly result from instantaneous dipole-dipole (London dispersion) forces. Van der Waals forces tend to be relatively short range (at distances less than a few nanometers (nm)) compared to electrostatic forces that are relatively much longer range. They are only significant if a particle is in very close proximity to another surface and these forces are affected in magnitude by particle shape. Higher area of contact and the greater the number of contact points per toner particle increases the magnitude of these forces. A perfect sphere on a flat plane has only one contact point and low area of contact, so the reader can appreciate that, theoretically, a sphere would be subject to a lower magnitude of Van der Waals force than a multifaceted particle with multiple contact points. Thus rounded toner is subject to lower adhesion forces than irregularly shaped tone.

Van der Waals forces affect not only the adhesion of toner to surfaces in the development system (developer sleeve, photoconductor, etc.) but also cohesion between toner particles. This can clearly affect the flow properties of the toner that, as we have already discussed, affect the developability of the toner.

Toner Particle Shape Control

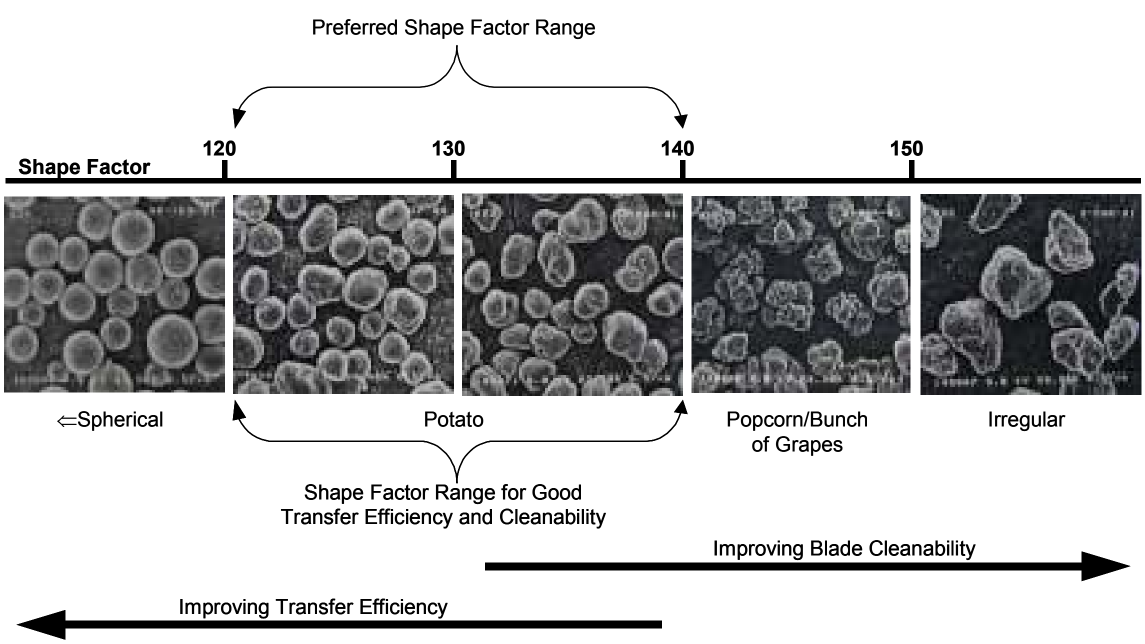
Compared to chemically prepared toner manufacturing methods, conventional toner manufacturing does not achieve a high degree of uniformity in composition or shape. One of the major features of CPT technology is the capability to select the required particle shape.

A common measure of the shape of toner is the shape factor. The shape factor of a toner particle is measured by comparing the square of the maximum length of a particle (ML) to the maximum projected area (A). The formula for shape factor is:

Shape Factor (SF) = $((ML)^2 / A) \times (\pi/4) \times 100$

By this formula a sphere has a shape factor of 100. A cube has a shape factor of 166.67. A right hexahedron with a maximum aspect ratio of 2:1 has a shape factor of 235.71. A regular tetrahedron with an equilateral triangular face has a shape factor of 314.29. Conventional toners when measured for shape factor typically give results in the range of 145 to 155, which describes rough and irregular particles. Thus toner conventional toner particles approximate to cubes in shape factor.

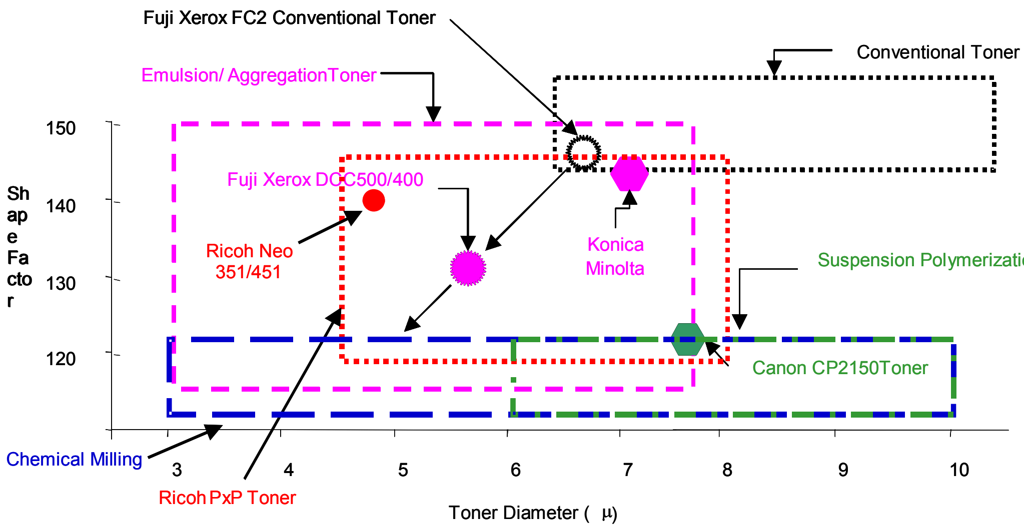
The diagram below shows SEMs of Fuji Xerox made EA toners of the same formulation but coalesced under different conditions leading to the creation of different shaped toners. An SEM of conventional toner is included for



comparison. Typically the shapes are referred to by the names of everyday objects such as potato, popcorn, bunch of grapes, raspberry, etc. As can be seen the range of shapes of the toners made runs from spherically shaped particles to potato shape to popcorn shape. None are however as jagged in morphology as conventional toner. The preferred shape factor range is 120 to 140 and is characterized as potato shaped. This represents the shape toner that has optimum transfer efficiency and cleanability using conventional blade cleaning technology.

<u>Particle Shape Control in Chemically Prepared Toner Technologies</u>

Different Chemically Prepared Toner technologies have different particle shape range capabilities. Suspension polymerization and chemical milling create predominantly spheroidal particles. Ricoh's "Ester Elongation Polymerization" or PxP process produces rounded, approximately elliptical cross section, spindle shaped particles that can be controlled to have a shape factor of about 120 to over 140. Emulsion Aggregation, or Latex Aggregation, as it is sometimes known can be used to manufacture toners with shape factors any where from close to 100, perfect spheres, to 150, the typical area for conventional toners.

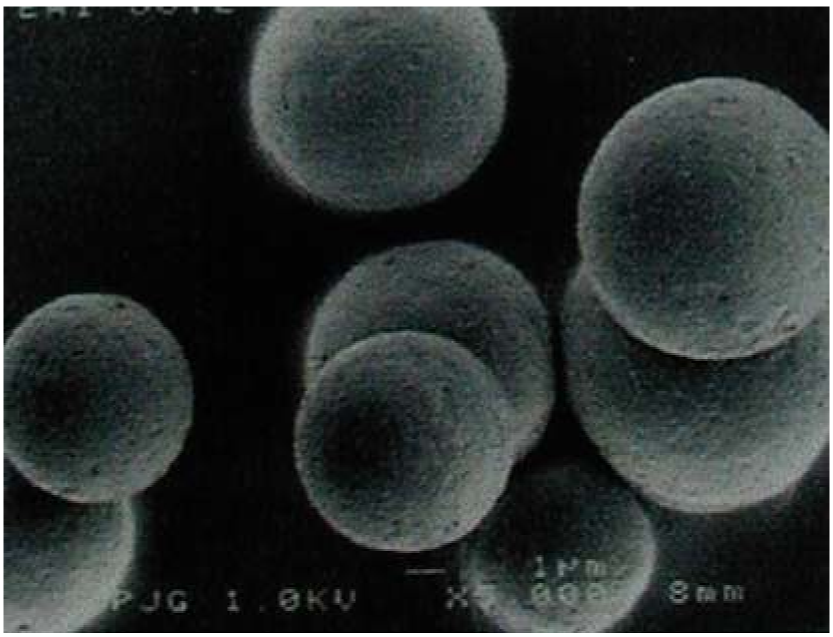


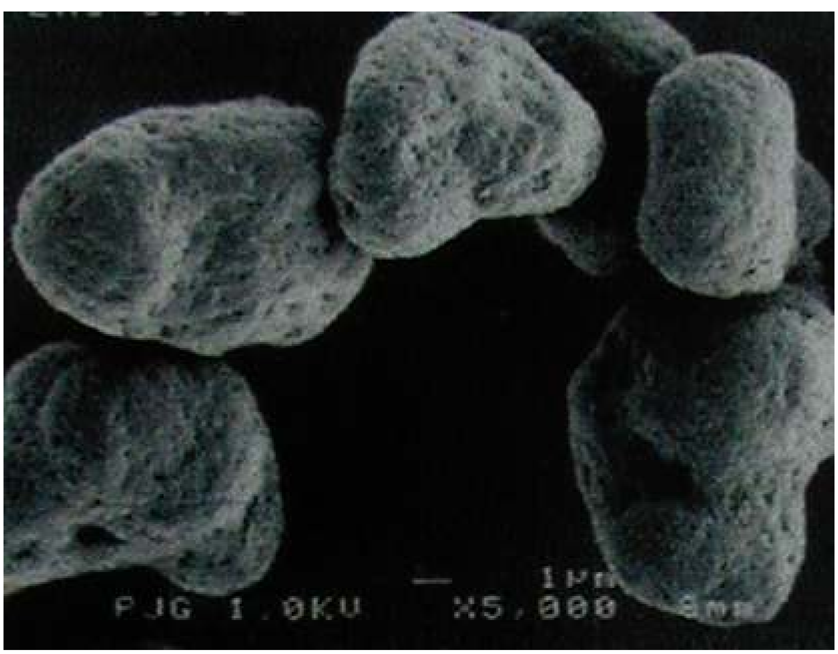
The following diagram developed initially by Fuji Xerox, and subsequently modified by the author, is a diagrammatic representation of the capability of these three basic chemically prepared toner technologies – suspension polymerization, emulsion aggregation (EA) and PxP as well as conventional toner manufacturing. This diagram compares the capability of competing CPT technologies in the fabrication of toner particles of a wide range of shape factors at a broad range of mean particle sizes as well as the particle size capabilities of the technologies.

Combination of Affects of Toner Shape

The shape of the toner therefore affects the toner physically as described and the combination of flowability, charging and adhesion force affects determine important performance factors such as transfer efficiency as well as blade cleanability. Thus with highly rounded toners with shape factors of close to 100 it is possible to achieve very high transfer efficiency rates, in excess of 99%. This level of performance translates into high yield and low cost printing solutions. In practice, toner manufacturers have adopted a variety of shapes much determined by the manufacturing method used.

Some SEMs of typical Chemical;ly Prepared Toner products are shown below.





Using EA technology the first picture shows a smooth surfaced spherical toner whilst the second shows a rougher surfaced potato shaped toner. The latter is typical of production toners from Xerox and Fuji Xerox.

Toner manufacturing in future will embrace the concepts and methods of manufacturing which best enable the control and manipulation of particle shape and chemically prepared toner manufacturing methods will increase in popularity for this reason.