Carbon Black Primer

Introduction

Carbon Black (CB) is a very important and irreplaceable component (also regarded as a filler) of the rubber and plastic polymer-based products. It is used as a substitute for the high value polymer for the purpose of improving the properties of the product in terms of strength, conductivity, etc. Therefore, carbon black is considered to be a very unique filler which reduces the product price and increases its quality. Due to the huge global automobile market the most prevalent CB application is for rubber tire manufacturing. Specialty conductive CB used for cable coating and other semi-conductive rubber applications is another important CB application due to its high-quality requirements and high market value.

Virgin CB is produced by incomplete combustion of fossil fuel such as gas and oil. This is a very "dirty" process since incomplete combustion of fossil fuel produces significant amount of NO_2 and CO_2 emission. Each ton of virgin CB produced results in more than 2 tons of CO_2 emission.

Consumption of tire making CB quickly depletes our world's precious fossil resources and keep the oil price rising. Our world has been in search of a cheaper and cleaner way to produce CB.

CB Morphology

CB morphology (i.e. its intrinsic form and structure) consists primarily of small particles of elemental carbon (C) with amorphous molecular structure, and a very small amount of other chemical elements such as oxygen, hydrogen and sulfur, referred to as impurities. Different CB applications tolerate and often require presence of certain impurities. For example, a significant

amount of silica is added to the tire filler in order to achieve desirable qualities required for the tire. Silica content in tire filler may be as high as 9% whereas pure carbon black would be 91%. Silica and metals are the major constituent of CB's ash content. The amount of ash content is determined by measuring the mass of the remaining CB material after thermal treatment.

Unlike tire making CB, only very low content of impurity may be present in the Specialty Conductive CB. For example, CB for cable coating can only have ash content between 0.1% and 0.5% in order to meet the specific application requirements.

The CB morphology is shown in the Transmission Electronic Microscope (TEM) image below of the recovered carbon black (rCB) produced with our G^{3}C system.
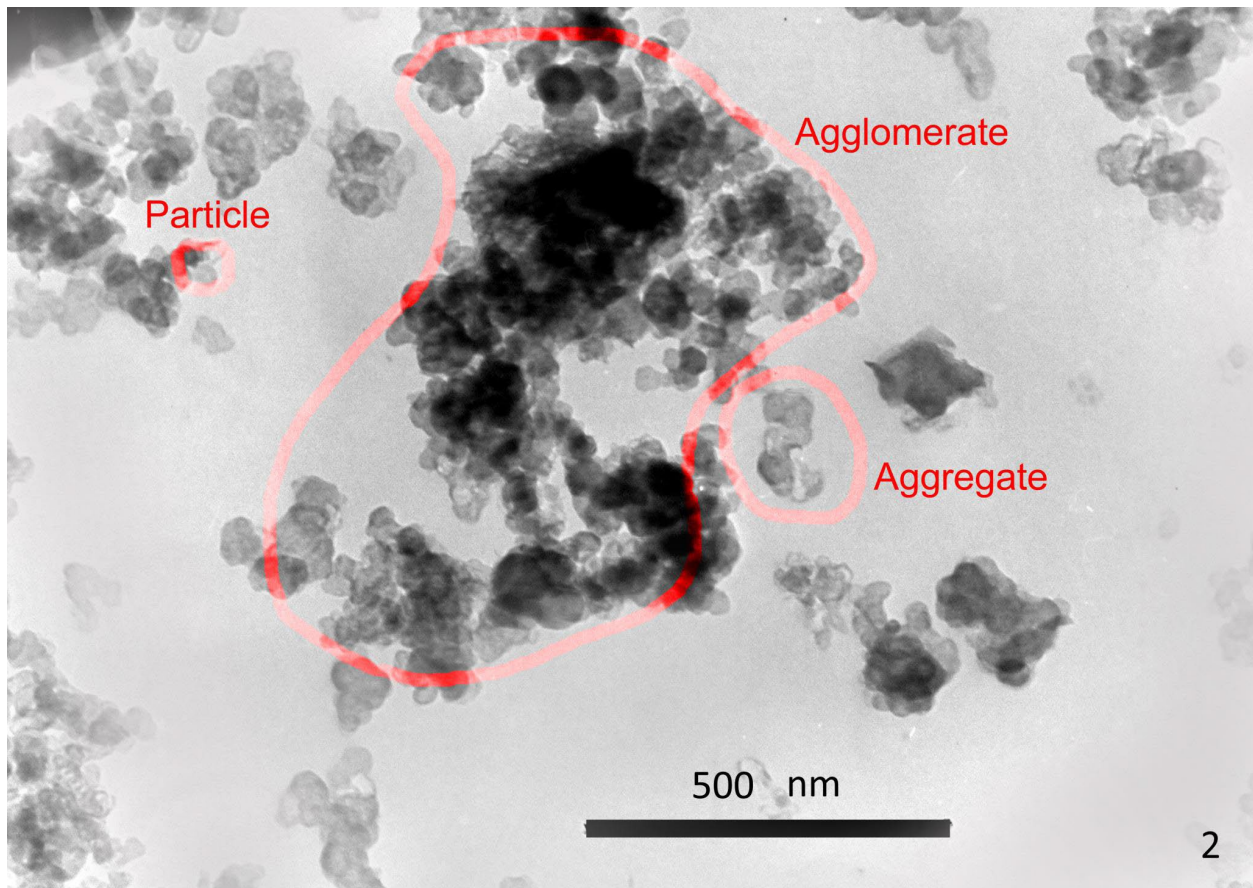
There are three distinct types of formation in the average CB product:

- **Particle** - is the smallest form of CB with the size in the 10-300 nanometers (nm) range. The distribution and the average value of the CB particle sizes are the two key parameters for CB grade classification. Higher grade CB generally has smaller particle size.
- **Aggregate** - is the smallest association of CB particles that exist individually in the polymer compound. It is a random association of multiple CB particles fused together forming a chain-like branching clusters. The size of the industrial grade CB aggregates ranges from 85 nm to 500 nm.
- **Agglomerate** - is the association of loosely bound (with weak association forces) but not fused aggregates. The size of the agglomerate ranges from a fraction of 1 micron to hundreds of microns and much higher (in case of pellets). The relative position of the aggregates within

the agglomerate may be changed or disassociated by external mechanical force, e.g. CB grinding/milling. Weak association forces are also used by CB pelletizing process. Pellets themselves are artificially created large agglomerates formed by the pelletizing process.

Carbon Black Properties

The specific grades of CB are defined according to the quality of the CB, i.e. carbon black properties. The two key CB properties are surface area and structure:

- **Surface Area** - is a key CB property that is directly related to the CB particle size. For a fixed amount of CB, the total surface area increases as the size of the CB particles decreases. The most accurate surface area test method is Nitrogen Surface Area Test or BET (Brunauer–Emmett–Teller) Test per ASTM D6556 specification. This test provides two values, N2SA and STSA - measured in m^2/g.

  - **Nitrogen Surface Area (N2SA)** aka **Total BET Surface Area** – is determined by measuring the amount of nitrogen adsorbed by the agglomerate surface plus nitrogen absorbed by the internal micropores.
  - **Statistical Thickness Surface Area (STSA)** aka **External Surface Area** is determined by measuring the amount of Nitrogen adsorbed by the agglomerate surface.
  - **Porosity**, the surface area associated with micropores, is determined by the amount of Nitrogen adsorbed by the internal micropores and is calculated as **N2SA** minus **STSA.**

  BET test requires relatively expensive apparatus, therefore, a simpler alternative Iodine Adsorption test (ASTM D1510) is often used. This test provides inexpensive approximation of BET Surface area under certain conditions.

- **Structure** - provides integrated characterization of CB aggregate morphology. CB structure is tested with Dibutyl Phthalate (DBP) Absorption test per ASTM D2414 specification and quality of the structure is measured by the Oil Absorption Number (OAN, measured in ml/100g).

Surface Area and Structure are the two key properties for CB grade categorization and the two most important qualities for all CB applications. There are a number of other CB properties that are important for specific CB applications. Such CB properties include but not limited to: Colorimetry (characterized by tests such as Jetiness and Tint Strength), Chemical Analysis (characterized by tests such as Volatile Components, Ash Residue, Moisture, Sieve Residue, Non-Dispersible Matter, Toluene Extract, Transmittance of Toluene Extract and pH), Appearance/Handling (characterized by tests such as Pour Density, Individual Pellet Hardness and Pellet Size Distribution).

Carbon Black Grades

CB grades are designated per ASTM classification standard D1754 for the purpose of identifying the property of the specific species of CB. The CB grades are identified by the two major CB properties, Surface Area and Structure. The diagram below shows the major tire making CB grades with the Horizontal Axis representing Surface Area and the vertical Axis representing Structure.

Tire Making Carbon Black Grades
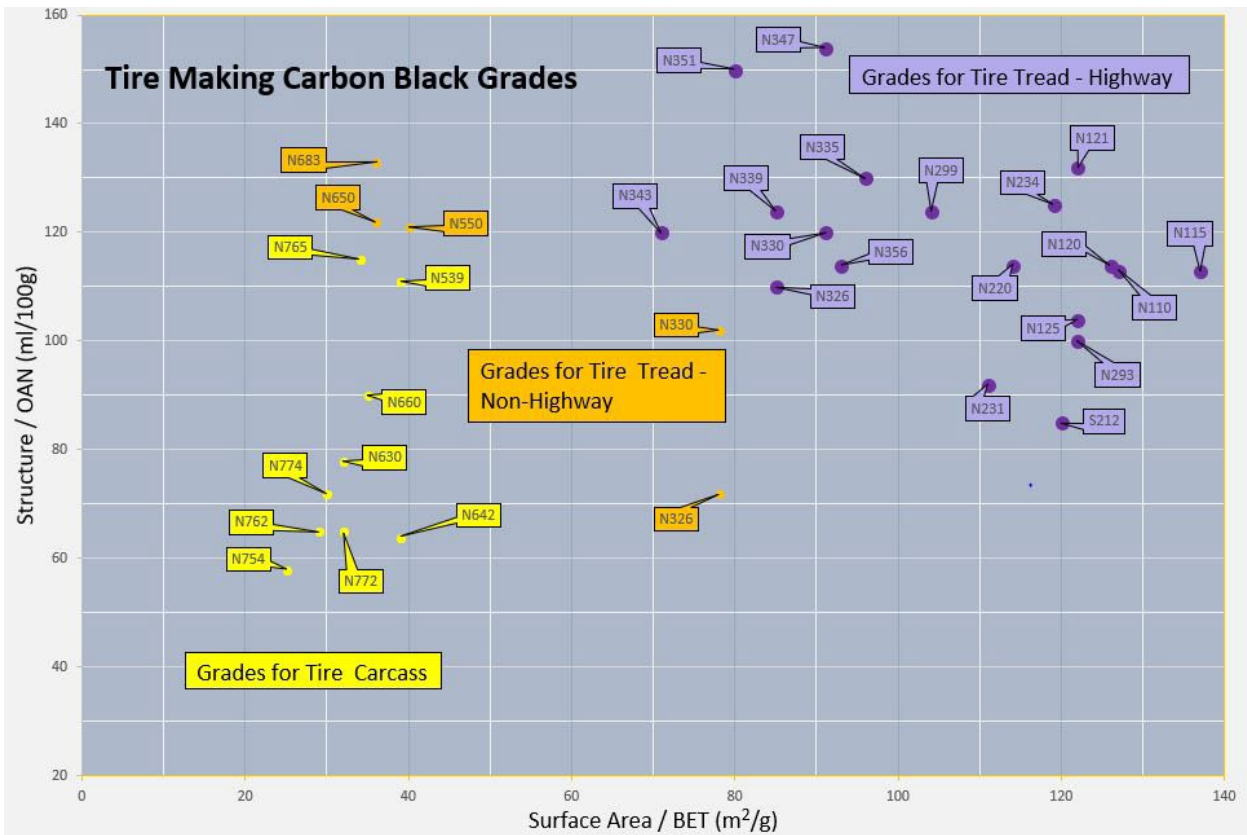
CB grades in the diagram are grouped into three categories:
- Yellow – CB Grades for Tire Carcass
- Orange – CB Grades for Tire Tread for Non-Highway Vehicles
- Purple – CB Grades for Tire Tread for Highway Vehicles

As per ASTM standard D3053 the CB grades used for tire treads have high BET surface area (≥70 m²/g). The above diagram also shows that the majority of CB grades used for tire tread have high structure (> 100 ml/100g), while majority of CB grades used for tire carcass have lower surface area (≤ 70 m²/g) and lower structure (≤ 100 ml/100g). Therefore, in order to produce rubber for the entire tire one needs use both low and high grades of CB.