PHYSICO-CHEMICAL AND STRUCTURAL CHARACTERIZATION OF CARBONS

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1. FROM COALS TO GRAPHITE

1.1. Definitions: the World of Carbons

Any coal or organic matter heated to a sufficient temperature in an inert atmosphere will progressively lose its atoms other than carbon and will become an artificial carbon material or "carbon". A similar process takes place to some extent in nature, where substances of biological origin are buried and may be transformed into coals of progressively higher carbon content under the action of temperature and also pressure and chemical agents. Coals and carbons can then be considered as members of a same family, which generate each other, the ultimate offspring being the graphite crystal.

It is however a very numerous family, and its genealogical tree is extremely complex, with many different places of birth, a lot of dead branches, and even some mutants.... A wide variety of physico-chemical methods are necessary to characterize the chemical constitution, structure, and properties of these solids, and to monitor their evolution along the path which may eventually lead them to more or less perfect graphite.

It is not even easy to give a precise definition of who belongs to the family. The term "carbon" usually refers to materials which are at least constituted of, let us say, 95 % atoms of carbon. But this dividing line is obviously very arbitrary and, although it keeps some coals in the carbon family, it leaves most of them outside. Since we are going to discuss the characterization of coals AND
carbons, this lack of an exact definition will not create any real difficulty.

Let us however note that diamonds are not generally considered as "carbons": carbon atoms in a carbon material are assumed to be predominantly linked by hybridized $sp_2$ bonds, in spite of possible exceptions in carbon films.

But it is necessary to start by reviewing briefly the main branches of the family.

First there are different starting materials:

1) LIQUID AND SOLID PRECURSORS (coals, natural biological materials or hydrocarbons, industrial organic substances, textiles) can be submitted to heat-treatments up to 1000–1100°C in reducing, oxidizing, or neutral environments. These CARBONIZATION processes yield COKEs, GLASS-LIKE CARBONS, or FIBRES. During the manufacture of cokes, the material may remain in the solid state throughout the whole treatment, and it may also undergo a transitory melting in the vicinity of 450–500°C: the resulting intermediate liquid is a MESOPHASE, with interesting anisotropic properties.

At higher heat-treatment temperatures (H.T.T.) the PRE-GRAPHITIZATION (up to 1600°C) and GRAPHITIZATION (up to 3000°C) processes yield PREGRAFFITIC CARBONS or ARTIFICIAL GRAPHITE.

2) GASEOUS PRECURSORS (evaporated carbon or gaseous hydrocarbons) can be pyrolyzed at various temperatures ranging from near room-temperature up to more than 1600°C and a very wide variety of PYROLYTIC CARBONS and CARBON BLACKS as well as FIBRES are obtained, according to the precise operating conditions (temperature, pressure, gas composition, gas flow, gradients, etc...). In the case of pyrolytic carbons, the process is called "chemical vapor deposition" (C.V.D.): it may be performed at relatively lower temperatures with the help of an electric discharge ("plasma-assisted CVD").

All these materials can of course be heat-treated at temperatures higher than their "temperature of deposition" ($T_D$) through a subsequent pre-graphitization or graphitization.

But the ultimate stage is not always graphite. Those carbon materials which can be eventually purified and organized in crystals of three-dimensionally ordered graphite are labeled "GRAPHITIZING CARBONS" or "SOFT CARBONS". The other carbons also undergo a progressive purification and ordering under the effect of the graphitization treatment, but, even at the highest H.T.T., they never reach the three-dimensional graphite stage: they are called "NON-GRAPHITIZING" or "HARD CARBONS".