

Manufacturing Process and Material Properties of Carbon and Graphite Materials

Carbon and graphite materials are manufactured according to processes based on conventional ceramic technologies. Raw materials such as petroleum cokes, pitch cokes, carbon black or graphite

materials with a defined grain size distribution are mixed with a thermoplastic binder at elevated temperatures. Coal tar or petroleum based pitches as well as synthetic resins are used as binders. Mineral

additives or metal powders can be employed to achieve special material properties. As an example, copper powder is generally used for the manufacture of carbon brushes applied in low voltage motors.

Material Processing and Mixing

Material processing and mixing at Schunk Kohlenstofftechnik is basically performed using computer controlled continuous processes. The grain size distribution of the processed raw materials is controlled by laser diffraction, mostly online.

The mixing process is carried out in double screw extruders according to specific parameters such as throughput, screw configuration and temperature profile.

Shaping

The ready-to-mold mixes are formed into "green bodies" by die molding, isostatic molding or extruding. The shaping process can be carried out at ambient or elevated temperatures; the pressure may vary between 2 and 400 MPa.

Baking

After the shaping process, the "green bodies" are baked. Depending on the type of material, dimensions and the required material characteristics, the baking process

is performed in continuous or batch furnaces applying different heating rates, maximum temperatures (up to 1200 °C / 2190 °F) and furnace atmospheres.

During baking, the binder is decomposed into volatile components and carbon. This process is called pyrolysis. The resulting binder coke ensures the integrity of the molded and baked blocks.

After baking, the blanks do not yet possess a complete graphitic structure. They are brittle and, generally, exhibit high mechanical strength and hardness. At this stage, the material is called carbon/graphite or "hard carbon". It demonstrates properties suitable for certain mechanical applications, such as sliding rings and bearings.

Graphitizing

For many applications, graphitic properties are required which are obtained through the process of graphitization, a second heat treatment at temperatures up to 3000 °C (5430 °F).

At Schunk Kohlenstofftechnik, graphitization is mainly performed by applying the Acheson process,

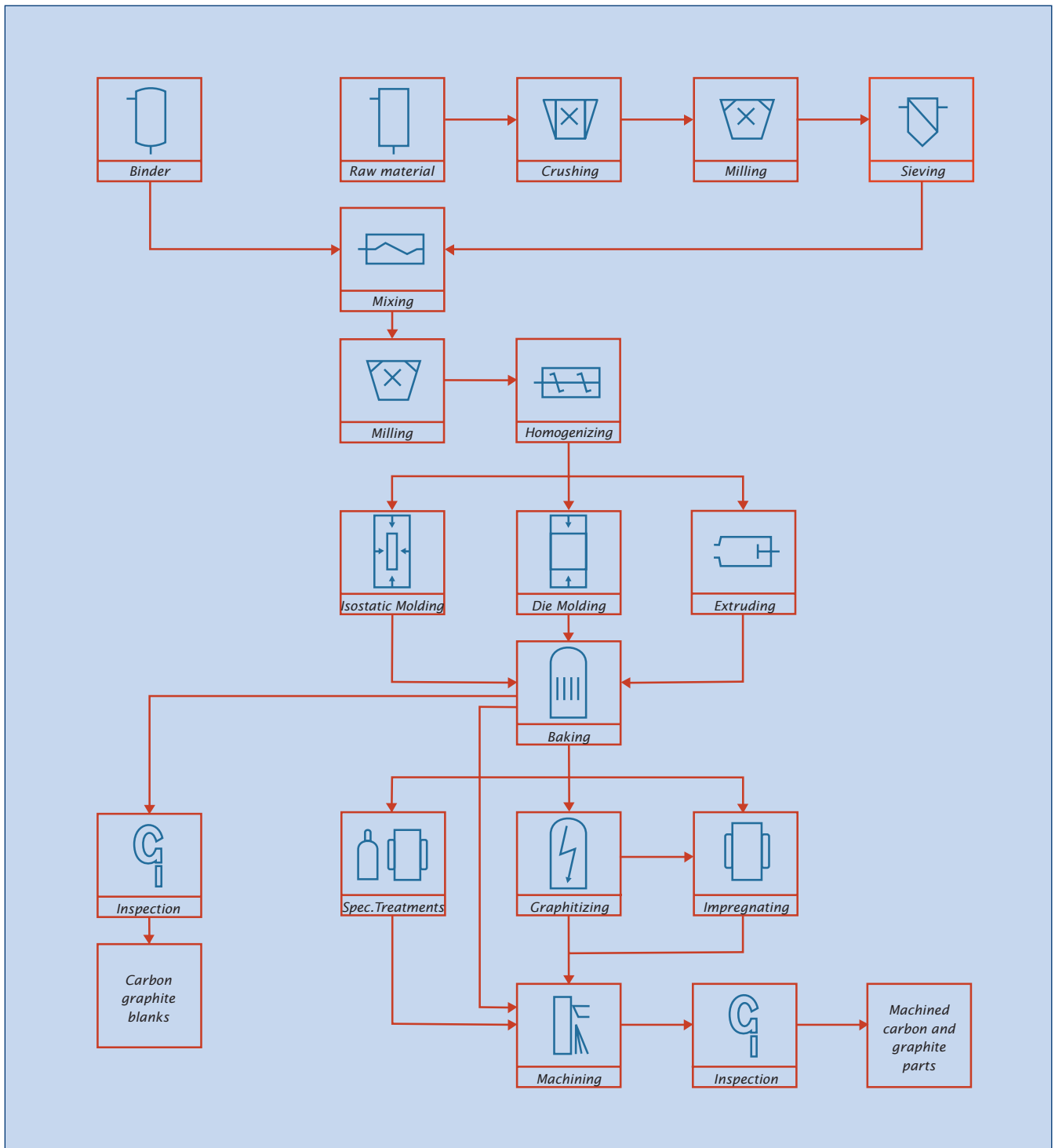
whereby the material to be graphitized is packed between two electrodes and connected as a resistance in the secondary circuit of a transformer. Thus, the graphitizing temperature is reached by resistance heating. During this process, recrystallization occurs, yielding in larger graphitic domains with a higher degree of orientation. The material properties of the graphitized blanks are defined by the structural properties of these graphitic domains. Graphitized carbon is called electrographite.

Electrographite materials generally possess excellent sliding properties, low electrical resistance, high thermal conductivity and an improved corrosion resistance. They are used for applications where enhanced sliding properties, high resistance to chemical attack and temperature cycling as well as a high purity are required as an individual characteristic or as a combination of properties.

Inductively heated graphitizing furnaces or vacuum graphitizing furnaces are frequently used for carbon fiber-reinforced carbon (CFRC; C/C) materials as well as when the highest purity is required.

The manufacturing process of carbon and graphite materials contains the following steps:

- Raw material processing
- Mixing
- Shaping
- Baking
- Graphitization (only for the production of electrographite)
- Special treatments such as impregnating, purifying, coating
- Final machining



Impregnating

In addition to the production process for the basic material, there are many processes to generate special properties for particular applications. By impregnation with synthetic resins, the porous structure originated by pyrolysis of the binder can be made impermeable to gas and liquids. By impregnation with metals, an increase in hardness and strength by a factor of 2-5 can be achieved.

Resin Bonding

Special properties can also be achieved by resin bonded carbon materials. Materials impermeable to liquids and gases can be produced without being subjected to the coking and impregnating process. Because they are not graphitized, such materials have moderate sliding properties, which can be improved by using natural graphite or synthetic graphite as raw materials.

Resin bonded carbon materials can only be used up to the curing temperature of the resin, generally 180 °C to 280 °C (350 °F to 530 °F). The production of low electrical resistance, resin-bonded materials is not possible because of the isolating properties of the resin.

Special Treatments

Out of a variety of special treatments the most important ones should be mentioned:

- Purification of graphite parts in order to obtain products of the highest purity
- Coating of the highest purity graphite with pyrolytic carbon (PyC) and/or silicon carbide (SiC)
- High-vacuum degassing

Due to the various possibilities of modifying carbon or graphite materials and optimizing their characteristics for special needs, the application fields for this material group reaches into all branches of technology and is still expanding.

Characteristics depending on Structure and Bonding

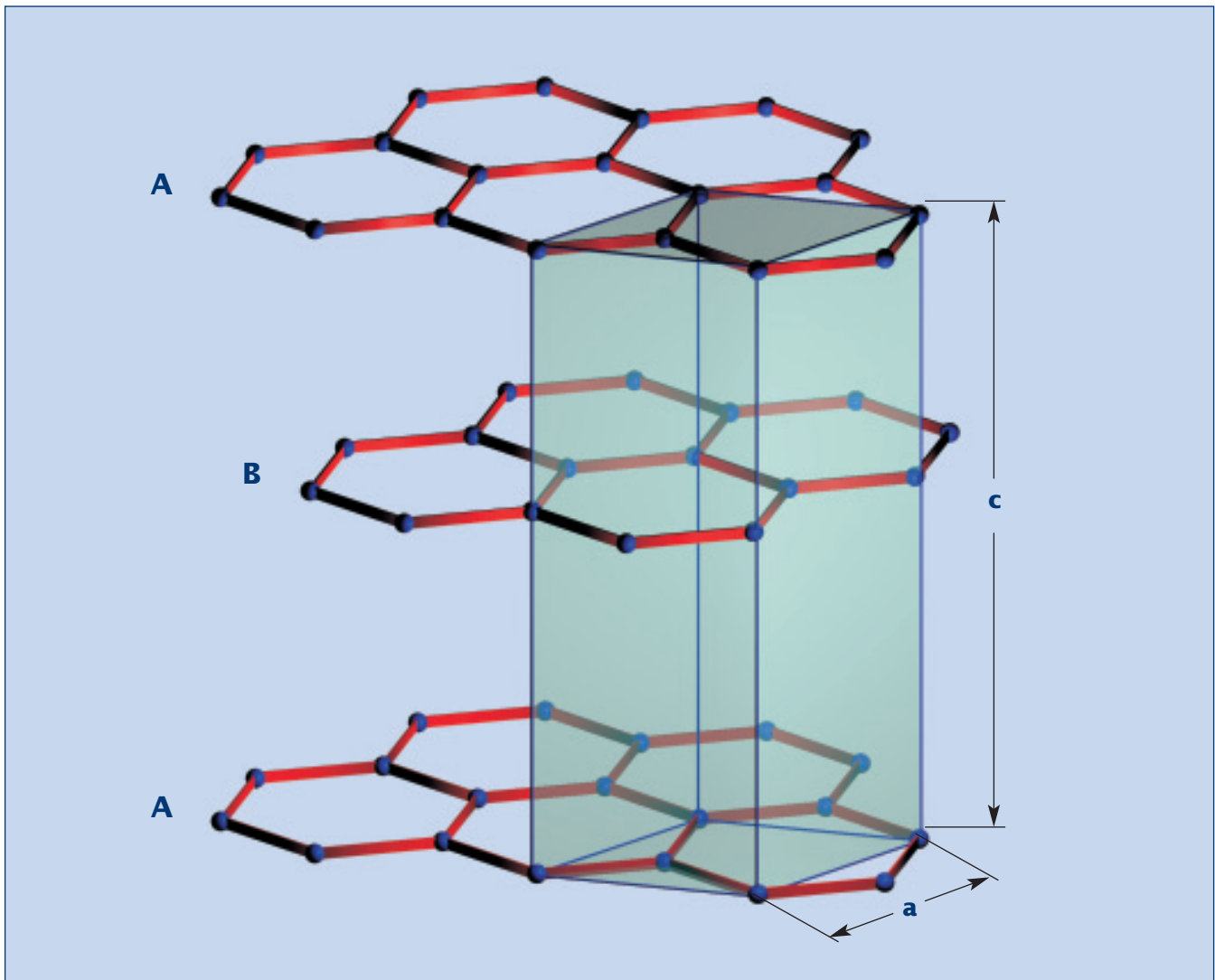
Based on the special bonding characteristics of the carbon atoms in the graphite lattice, graphite crystallizes in a hexagonal layer structure. The enhanced sliding properties, the anisotropy of electrical and thermal conductivity as well as the coefficient of thermal expansion are characteristics which depend on structure and bonding of the graphite.

The chemical properties of carbon materials are also determined by the bonding conditions of the carbon atoms within the lattice. Due to the high strength of the covalent bonds within the lattice layer, carbon materials exhibit a high resistance to acids, bases, gases, melts, etc.

The resistance of carbon materials is only limited by strongly oxidizing media and oxygen. In oxidizing atmospheres carbon graphite materials are stable up to 350 °C (660 °F),

whereas graphitized materials start to be oxidized at 500 to 600 °C (930 to 1110 °F). Up to these temperature limits at least the short-term service will not be restricted by oxygen attack.

Details on the resistance to chemical attack encountered in practice are given in our brochure "Chemical Resistance" (39.12e).



Graphite structure

Process dependent Properties

In addition to the properties depending on structure and bonding, carbon materials show characteristics which are related to the manufacturing process. Carbon manufactured according to the production method described above will have a polygranular and polycrystalline microstructure. Frequently, the microcrystallites already present in the grains of the solid starting materials are randomly oriented, so that nearly no remaining anisotropy of the crystallites is measurable.

Porosity is a property particularly influenced by the manufacturing method and can be varied between 0 and 50 %. The porosity can be defined by the pore volume and the pore size distribution, both being characteristic for different material and production methods. In general, there are both open and closed porosity. Open porosity can be filled by impregnants, whereas closed porosity cannot.

Due to the porosity and the different graphitizability of various carbon materials, all industrially manufactured polycrystalline carbons exhibit a lower bulk density than that which is calculated theoretically based on the ideal crystal structure of the graphite. Depending on the production method, bending strength and compressive strength can be varied within wide limits. The bending strength may vary from 10 to 150 MPa.

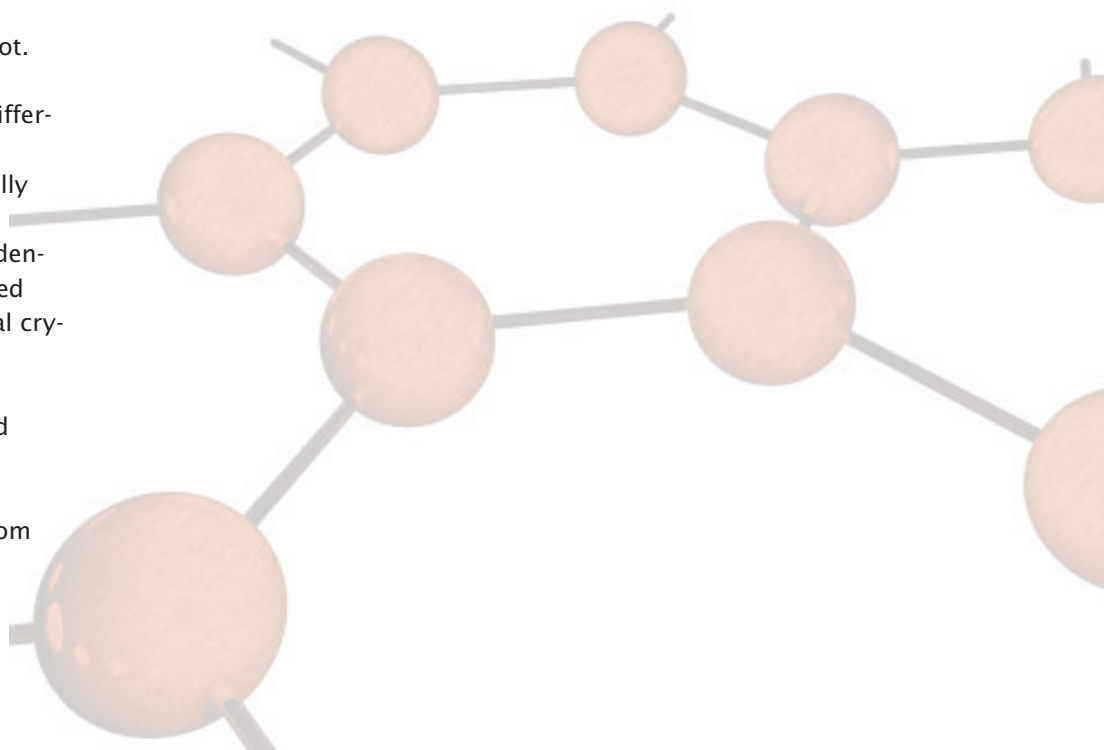
Methods for the Determination of Material Properties

First, those properties should be mentioned which are typical for each grade and can easily be determined:

- Specific electrical resistance (according to DIN 51911)
- Hardness Rockwell (according to DIN 51917)
- Bulk density (according to DIN EC 60413, DIN 51918)
- Bending strength (according to DIN 51902)
- Ash content (according to DIN 51903)

These properties allow for rapid identification of the material grade and for quality inspection. They serve as a basis for delivery contract agreements between customer and manufacturer.

The testing methods mentioned above are summarized with special reference to carbon brushes in DIN EC 60413. Further standards for the investigation of carbon materials can be found in the DIN Standard Series 51901 through 51940.



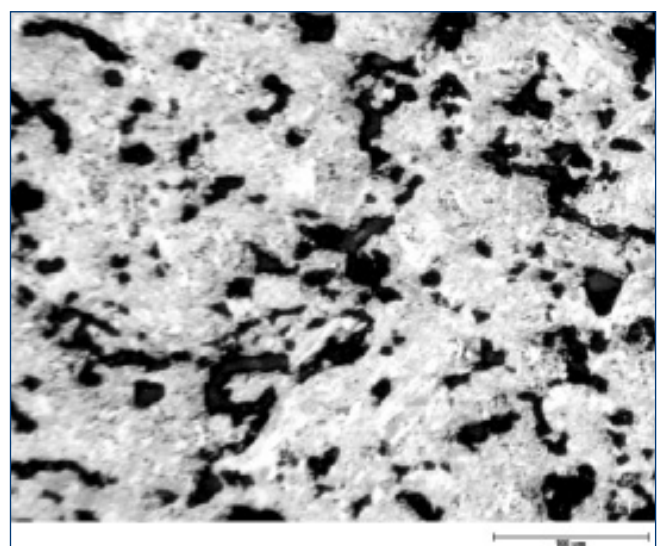
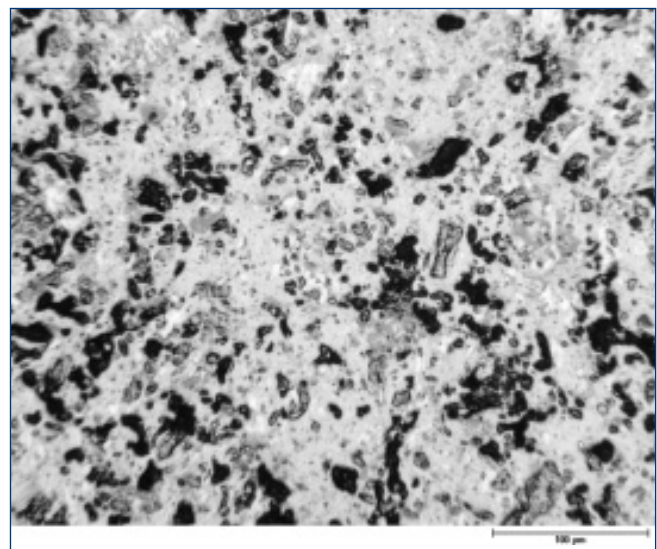
Further Characteristic Data

In addition to the above, further characteristic data can be determined which require a fair amount of measurement, however, knowledge of which is vital for certain applications as well as for internal investigation purposes. These are, for example, Young's modulus, tensile and compressive strengths as well as thermophysical data such as the coefficient of thermal expansion, thermal conductivity and specific heat capacity.

Usually, it is not sufficient to know just the porosity of a carbon or graphite material in order to characterize its impregnation behaviour. It is often necessary to determine the pore size distribution, to examine the microscopic structure of the material and also, possibly, the wetting behaviour of various impregnants.

Furthermore, the influence of the impregnation process on the material properties (e. g. on the oxidation resistance and on the permeability) is of interest (e. g. oxidation resistance, permeability). Not all of those properties are routinely measured, as this would create unnecessary laboratory expense. If required, special information will be gladly given on request.

Micrographs of carbon structures with different porosities and grain size distributions

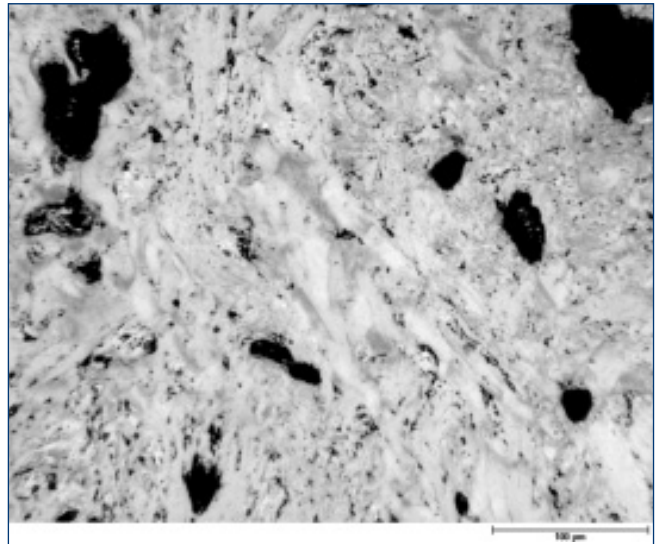


Application related Examinations

The properties of a specific product are measured with reference to special fields of application in addition to the material properties previously mentioned. Tests could cover the determination of the:

- Coefficient of friction against various materials
- Contact resistance of a sliding surface
- Wear rate under various load conditions
- Adsorption of gases
- Wetting behaviour with melts
- Radio interference behaviour with an electrical sliding contact
- Dependence of electrical resistance on temperature.

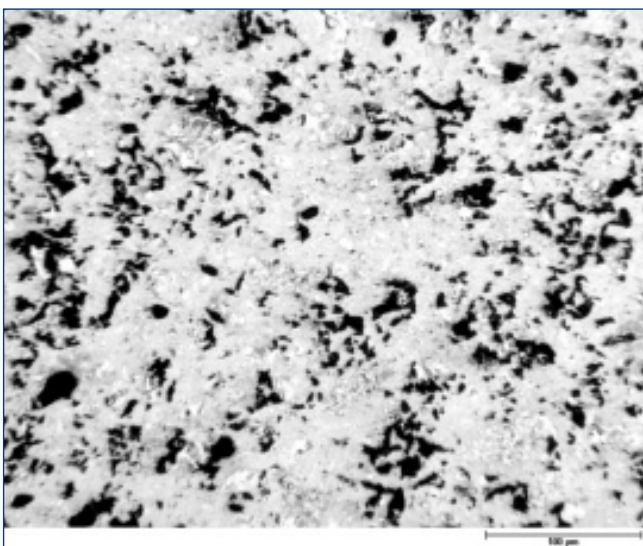
Polycrystalline graphite



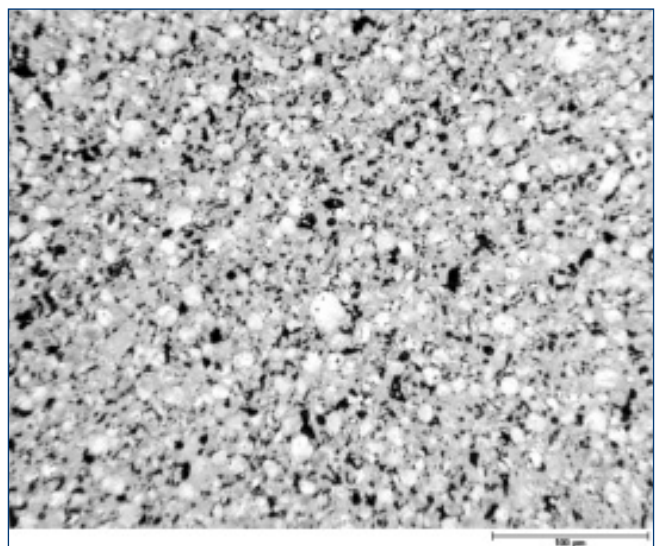
coarse-grained FE 934



fine-grained FE 219



fine-grained FE 679



finest-grained FE 779

Technical Carbon

Carbon and graphite materials are generally manufactured in polygranular and polycrystalline form. This means that the blanks show a random orientation of crystallites. Due to this microcrystalline structure, a macroscopic blank does not show the typical anisotropic properties of a graphite single crystal. With polycrystalline materials, the extremely high anisotropy of the electrical conductivity or coefficient of thermal expansion is greatly reduced or nonexistent. The anisotropy of properties which occur in polycrystalline carbon materials does not only depend on the properties of the raw materials, but also on the molding method. Isostatically molded carbon materials, for example, show little or no anisotropy, whereas uniaxially or biaxially molded parts exhibit increased anisotropy. The data given for properties parallel and perpendicular to the molding direction vary and are, therefore, indicated separately.

Another form of technical carbon or graphite is pyrolytic carbon or graphite. This material is deposited from a carbon-containing vapour phase onto a heated substrate by chemical vapour deposition (CVD). The properties of these materials correspond much more to those of single crystals.

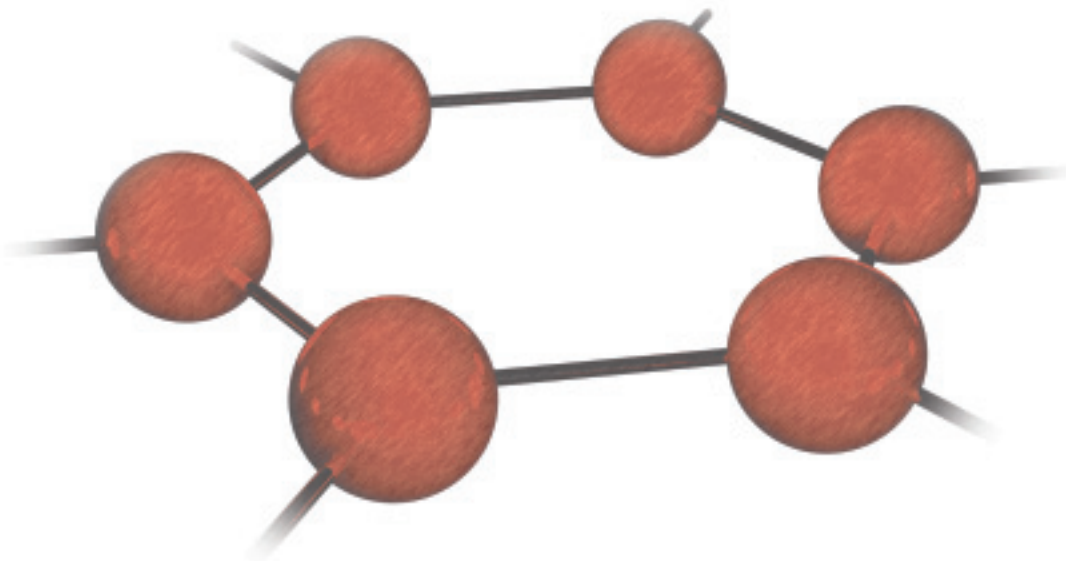
As the manufacturing process is very expensive, these procedures are in general only used for surface modification of standard polycrystalline materials, e. g. to achieve a low gas permeability or to produce a wear resistant surface. Solid pyrolytic graphite is used in only a few cases, e. g. for the manufacture of high capacity vacuum tube grids.

An additional class of technical carbon materials are carbon or graphite fibers. They are manufactured by pyrolysis of polymer fibers, preferably polyacrylonitrile (PAN), or of special pitch based fibers.

Carbon fibers are used for the reinforcement of polymers (carbon fiber-reinforced polymers; CFRP), carbon (carbon fiber-reinforced carbon; CFRC, C/C), ceramics (ceramic matrix composites; CMC), and metals.

These composites are normally used when high stiffness and strength together with low weight play a decisive role. Typical applications of CFRP are sporting goods and components for aviation and space technology which are not submitted to high temperatures. For high-temperature applications, e. g. in the semiconductor industry or furnace construction, C/C is the accepted material.

Another and less expensive form of carbon fibers is carbon felt which is used as a thermal insulation material.



Application Fields of Carbon and Graphite Materials

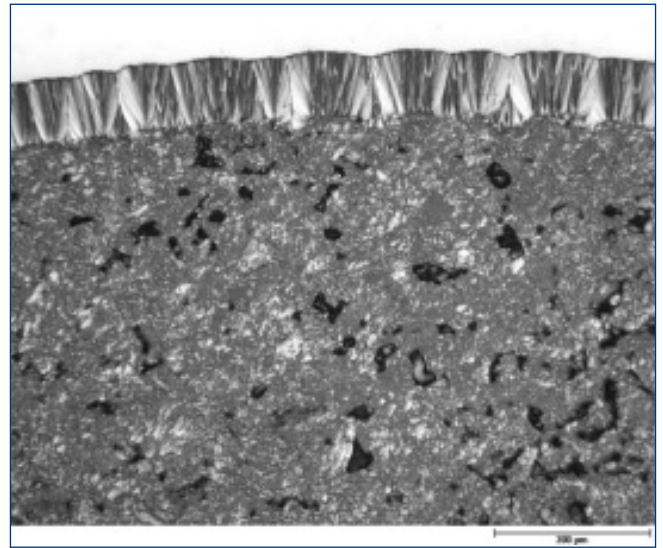
Due to their special properties, Schunk carbon and graphite materials are used for electro-technical products, components in mechanical engineering, the semiconductor industries, and for medical technology.

Details on the particular properties of the products for the various applications are given in our special brochures.

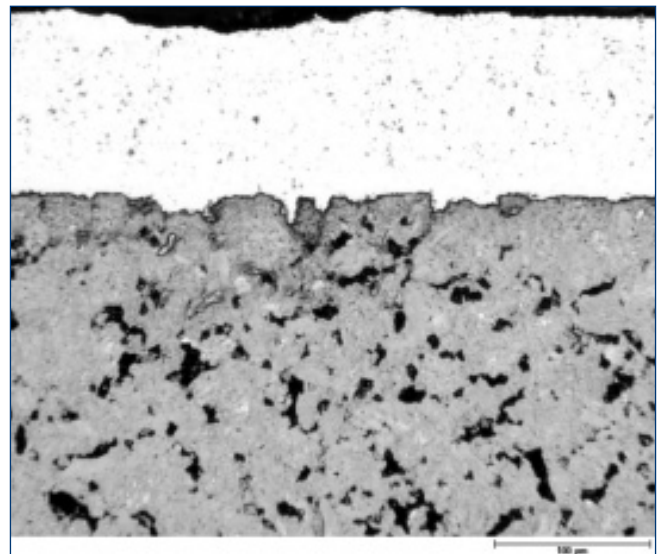
Schunk Material Codes

The Schunk material code is based on an alphanumeric system. The different groups of Schunk carbon materials are identified by one or two initial letters of the grade code. Materials for carbon brushes have only one letter to denote the grade category. All other materials are denoted by two letters, in that „F“ as the first letter indicates mainly mechanical application.

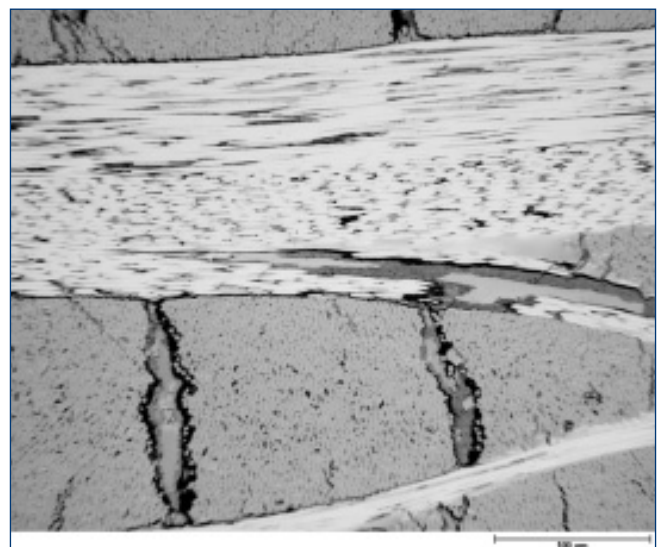
The two figures following the initial letters identify the different grades within the material groups. Depending on the material, a third figure indicates special manufacturing procedures. Additional processing steps such as infiltrations with metals, resins or special salts are indicated by a final letter/figure combination.



Electrographite with PyC layer



Electrographite with SiC layer



Texture of a C/C material

Material Code – Grade Categories

A	natural graphite / copper
B, C	natural graphite / copper babbitt metal alloy
E	electrographite
F	natural graphite, resin-bonded
H	carbon graphite
K	natural graphite / copper, pitch-bonded
L	carbon graphite
S	natural graphite / silver
U	special material
BH	carbon graphite, material for pantographs
WH	carbon graphite, resistance material
FE	electrographite
FF	resin bonded materials
FH	carbon graphite
FR, FP,	high purity electrographite
FG	highest purity electrographite
CF	fiber-reinforced material
FU	special material

The most Important Special Treatments

A	antimony impregnation
B	impregnation with lead-antimony
C	copper impregnation
D	lead-bronze impregnation
F, H, V	impregnation to improve the operational behaviour of carbon brushes
G	high vacuum degassing
M	bonded laminated carbon brushes (sandwich)
Q, M, PS	salt impregnation
R	X-ray inspection
S	pyrolyzed impregnant
T	impregnation to increase the abrasion capacity of carbon brushes
U	ultrasonic dedusting
X, Z, ZP	resin impregnation
Y	resin impregnation, pyrolyzed

Schunk Kohlenstofftechnik GmbH

Rodheimer Strasse 59
35452 Heuchelheim
Germany

Phone: +49 (0) 641 608 0
Fax: +49 (0) 641 608 1436

www.schunk-group.com
E-Mail: research.skt@schunk-group.com