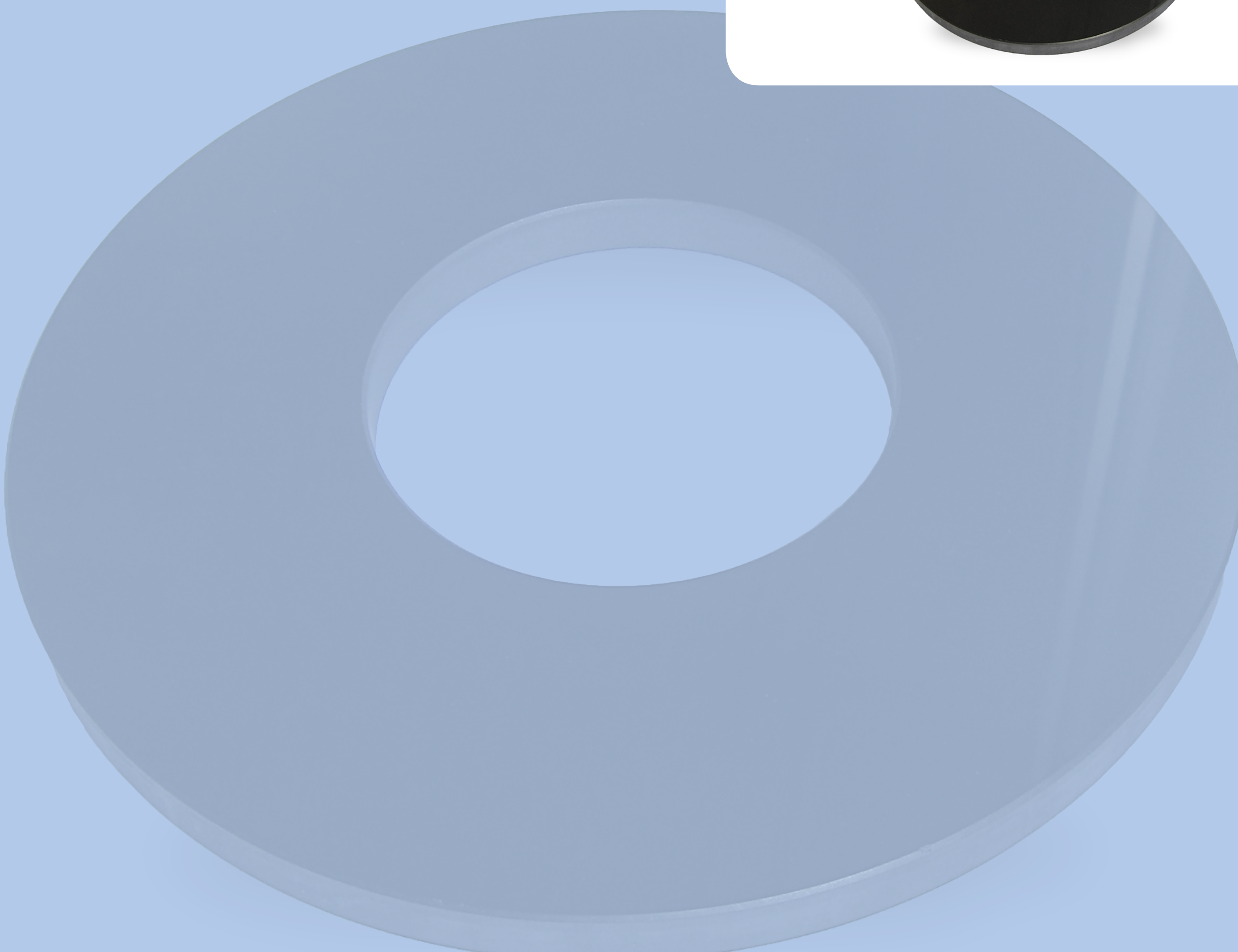
Carbon Tribology



Morgan Advanced Materials

SEALS AND BEARINGS

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Morgan Advanced Materials is a global materials engineering company which designs and manufactures a wide range of high specification products with extraordinary properties, across multiple sectors and geographies.

From an extensive range of advanced materials we produce components, assemblies and systems that deliver significantly enhanced performance for our customers' products and processes. Our engineered solutions are produced to very high tolerances and many are designed for use in extreme environments.

The Company thrives on breakthrough innovation. Our materials scientists and applications engineers work in close collaboration with customers to create outstanding, highly differentiated products that perform more efficiently, more reliably and for longer.

Morgan Advanced Materials has a global presence with over 10,000 employees across 50 countries serving specialist markets in the energy, transport, healthcare, electronics, security and defence, petrochemical and industrial sectors. It is listed on the London Stock Exchange in the engineering sector.

MORGAN ADVANCED MATERIALS
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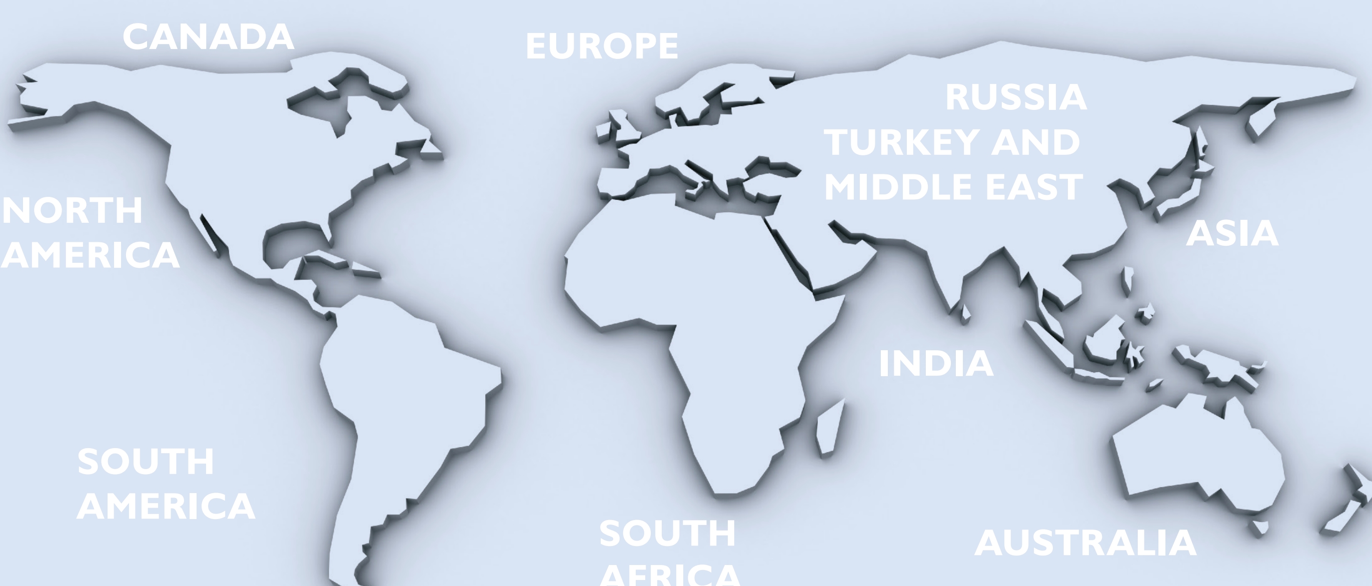


Carbon Tribology

1. Introduction

Technical developments today are directed more towards low maintenance or maintenance free machines, plants and equipment. In order to achieve the ever increasing reliability requirements even more attention must be given to moving machine-elements such as seals, bearings etc.

In most cases a sufficient supply of lubrication can be achieved with an acceptable expenditure, but over longer periods this could not be guaranteed due to insufficient re-lubrication. For this reason more reliable gliding materials were developed in the past few decades which either contained the required lubrication or where the dry-running condition had no influence on the reliability of the part. In this case carbon plays a very significant role due to its extraordinary properties.

In these times where environmental issues are becoming more and more important not only advantages due to carbons reliability and longer life in wear systems are becoming more apparent but also the use of machines without lubrication have added cost advantages both to the environment as well as to the company due to no oil disposal. Special acknowledgement and increasing importance goes to the economic branch which is combined under the term tribology.

2. Tribology

The term tribology was first used by Prof Jost in a Lubrication report by the British educational ministry in 1966 and is being used world wide ever since.

Definition

Tribology = The science and technology influencing two surfaces moving relative to each other and the related problems.

The job of the user or triboligist is to deal with friction and its effects on wear systems, for this purpose it is also necessary to recognise at an early stage wear procedures which affect machine element surfaces moving relative to each other and to understand mutual effects on operating conditions in an effort to optimise problem solving.

At Morgan the above mentioned tasks are carried out by Sales Engineers, Application Engineers and Research and Development Engineers. Tribology applies to almost all products offered by the Morgan company.

The field of tribology is very large and complex and can not be explained in great detail in such a short report. For this reason this report should be seen as an introduction to tribology, with the aid of examples as a means of understanding tribology and its relationship to carbon technology.

The current importance of tribology, especially in Germany, is reflected by the extent of Government sponsored projects in progress. The Government body responsible for such projects in Germany is known as the BMFT (Bundesministerium für Forschung und Technologie).

One such study by the BMFT carried out in Germany in 1994 concluded that economic losses arising from friction, wear and corrosion were at a level of 4.5% of the Gross National Product, this amounts to a total between approximately 45 and 50 Billion □ per year. These results emphasize once again the necessity to consider methods of wear reduction through the use of lubricants and wear resistant materials.

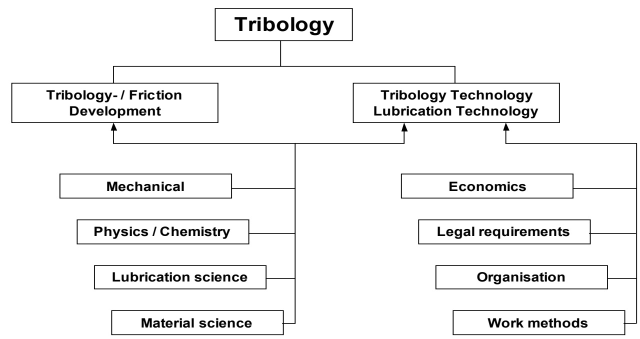


Fig 1: Technical departments involved in tribology

3. Friction

3.1 General

Generally friction can be defined as the mechanical resistance between two surfaces moving relative to each other. Sliding or contact friction is closely connected to a loss in mechanical energy, this is evident with a temperature increase of the mechanical elements.

Static friction causes no energy loss. Friction is not always a disadvantage for example in force-locking connections or friction drives cases friction has great advantages. (most successful application area of carbon). For a better understanding of the different friction conditions they have to be looked at a little more closely.

3.2 Types of friction

3.2.1 Static Friction

The friction force F_R can be calculated by multiplying static friction coefficient μ_0 with the normal force F_N.

$$\boxed{F_R = \mu_0 \times F_N}$$

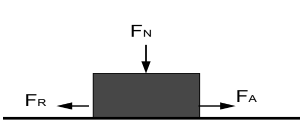


Fig 2: Static friction

While the friction force F_R is greater than the driving force F_A there will be no movement. When F_A is greater than F_R then the surfaces begin to slide over each other. i.e. relative movement between surfaces occurs.

3.2.2 Friction coefficient

With initial movement the static friction $\mu 0$ converts into the smaller sliding friction μ.

Friction condition	Lubrication layer	Friction coefficient μ
Boundary friction	-	0,1 - 0,25
Mixed friction	partially lubricated	0,01 - 0,2
Fluid friction	Lubricant	0,01 - 0,1
Rolling friction	Rolling element	0,001 - 0,01
Air friction	Gas, Air pressure	0,0001 - 0,0005

Table1: Magnitude of Friction coefficient in various Friction conditions

3.2.3 Friction conditions

The various friction conditions can be represented on a Stribeck chart. This chart shows the various stages of friction conditions and friction coefficients during the start up of a hydrodynamic bearing.

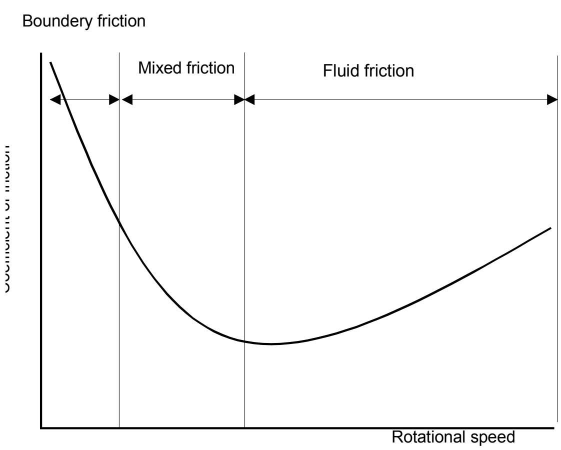


Fig. 3: Stribeck curve and friction conditions in sliding systems

3.2.4 Boundary friction (solid-state body friction)

When the rotational speed equals zero there is solid-state body contact, therefore after overcoming the static friction there is solid state body friction or boundary friction. Through increasing rotational speed the lubricant or fluid on the sliding surface is drawn into the gliding gap between bearing surface and shaft.

3.2.5 Mixed friction

The solid-state body contact as well as the lubricant takes part in the friction condition. Through an increasing rotational speed an increasing amount of lubricant is drawn into the gap and the proportion of the solid-state contact decreases due to the formation of a hydrodynamic supporting pressure.

3.2.6 Fluid friction

The friction coefficient μ drops and the shaft floats. The point with minimal friction coefficients is the transition point between mixed friction and fluid friction (hydrodynamic friction) which means the solid-state body contact disappears and the complete separation of the surfaces through lubricants starts.
Tribologicaly stressed carbon machine elements are used in all friction states favourably in machines and equipment where solid-state body contact and mixed friction are dominant.

4. Tribological systems

Every friction contact can be reduced to four elements of the tribological system:

- base body
- counter face body
- lubrication layer
- working medium

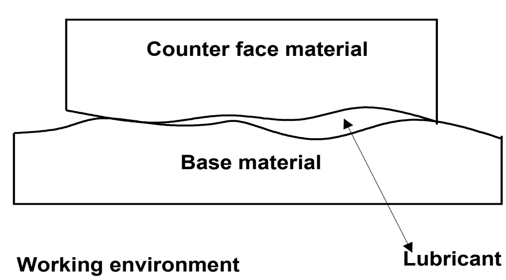


Fig. 4: The tribological system according to DIN 51320

Among others a lubricant or the medium surrounding a bearing is used to separate the base body and the counter face body, to increase the specific strain and to reduce wear.
Working mediums are among others:

- chemicals e.g. acids or alkaline solutions
- solvents
- paint
- vacuum

Alternating effects of externally acting elements depending on their magnitude and frequency are important for the wear behaviour of tribological systems. The alternating effects can take different forms, an overall view is shown in graph 5.

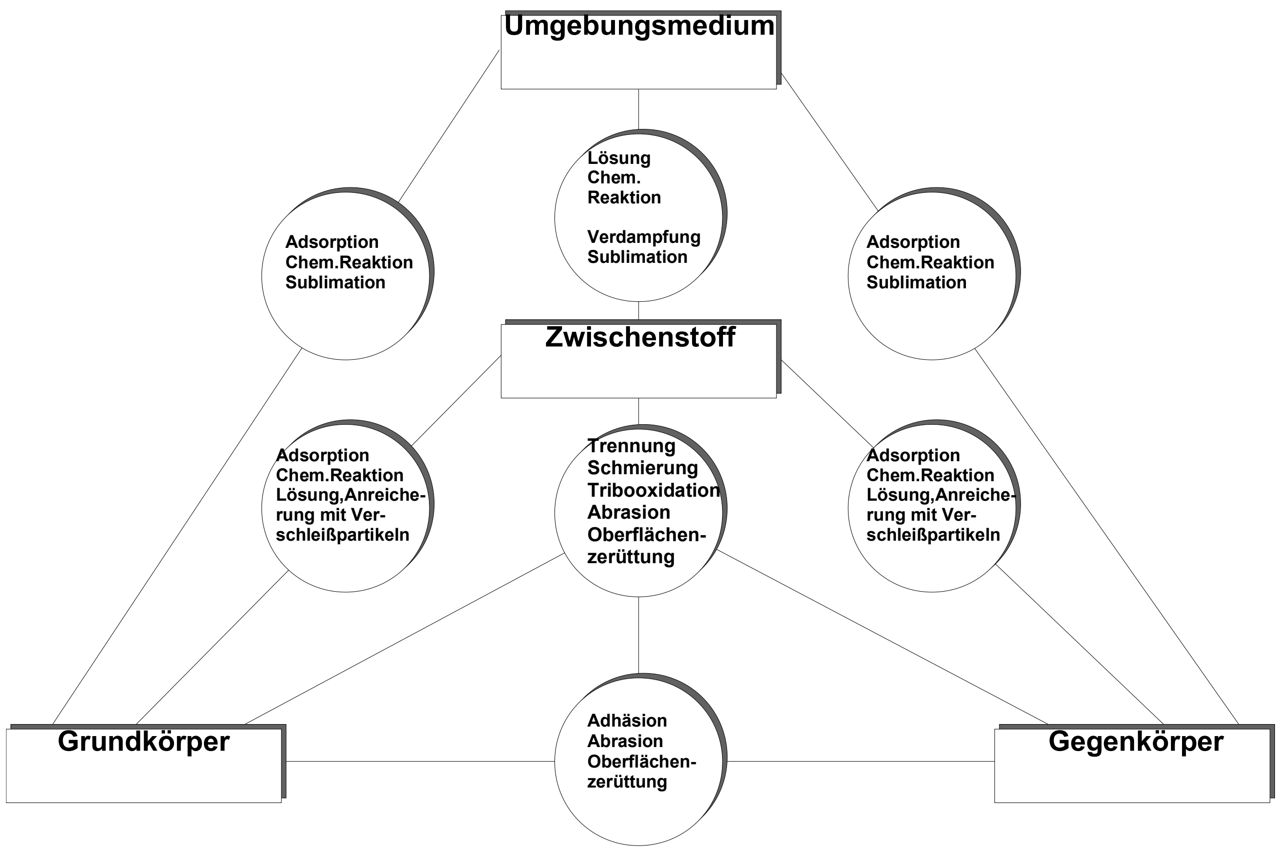


Fig. 5: Alternating effects between elements of a tribological system

5. Wear

Wear is defined as the process of a continuing loss of material from the surface of a solid- state body due to tribological use. Wear results from the combination of all elements of the tribological process that are taking part in the wear process. The main aim of all tribological efforts is their minimisation.

5.1 Wear mechanisms

5.1.1 Adhesion

Creation and separation of atomic bindings between base body and counter face body. Adhesion is a cause of corrosion. Those can occur when two sliding partners due to defective lubrication are separated through lubricating film which is too thin.

5.1.2 Abrasion

Cracks and micro cracks of base bodies due to hard roughness points of the counter face body or hard particles in the lubricating layer.
Hard particles act abrasively and lead to material removal on the surface. It can be often seen with the use of carbon lubricants.

5.1.3 Surface disintegration

Creation of cracks and crack growth until the splitting off of particles due to changing mechanical tension, which are active in the surface areas of base body and counter face body.

5.1.4 Tribooxidation

Chemical reaction of base body and or counter face body with components of the lubricating layer or the working medium due to friction.

5.1.5 Wear reduction

The effects of sliding friction are to increase temperature of the contact area and thus the wear of the contact bodies. Both occurrences are undesirable and must be limited, friction results in the loss of energy and wear leads to loss of material which can possibly result in the destruction of machine elements.
To retain the geometric form of the machine elements, e.g. to reduce the ware of the contact partners surface, the sliding partners must be separated by a lubricant during tribological contact. This can be achieved by means of a closed fluid film or through a transfer film in case of carbon materials.

5.1.6 Dry lubrication

In contrast to hydrodynamic lubrication, where a complete separation of the contact areas is provided by a viscous or consistent medium, there is the possibility of separating surfaces through dry lubrication.
Carbon with its form and abilities is the best known dry lubricant.

6. Solid lubrication carbon graphite

For many technicians and engineers carbon is often a secondary machine element. The material is unknown to many even though they are searching for solutions for their tribological problems and are not aware of the excellent qualities of this extraordinary material.
To find the markets where such problems occur and responsible technicians is the job of our sales engineers.
People with no knowledge of this material can have no understanding of the technology associated with 'black' material.

6.1 History

The history of the industrially used artificial graphite started with the development of electric machines. The first electric drive units equipped with a commutator or a slip ring, had a brush like device made out of metal threads or fabrics to conduct electricity. These brushes were very inefficient.
Only with the 'invention' of artificial carbon, by the Englishman Fobes around the turn of the century, was a suitable material found for conducting electrical impulses from moving to stationary machine parts. Many years later the use of carbon for other areas such as mechanical purposes was discovered.
The use of carbon parts in steam turbines was first mentioned in 1910. Scott and Bates published a US patent for a metal impregnated carbon grade for seals in 1933. Around 1950 the use of carbon as a tribological material expanded continuously. This development was triggered by an increasing demand in the Aircraft industry and the chemical industry.
Many working areas which previously could only be served by oil lubricated materials, now opened opportunities for the use of carbon. Worth mentioning are axial seals, that have been practically applied since 1940 thus entirely reducing the application opportunities of packing boxes apart from a few isolated cases. The proportion of rotating shafts which are being sealed by sealing ring seals is today in highly industrialised countries 80-85 %. Today in a large amount of tribological systems carbon can no longer be replaced. It is an established partner in friction systems and is dominant in lubricant free sliding pairs.
The function guarantee of tribologically used machine parts requires a particular combination, aimed at the requirements of the friction partners.
The optimisation in respect to

- wear and friction
- stability in the vacuum
- oxidation resistance under extreme temperatures

will be the primary role in the future development of the modern construction material carbon.

6.2 Definition

Carbon products for mechanical applications can be divided into 3 main groups:

- Carbon graphite
- Graphite
- Resin bonded graphite filled

6.3 Raw materials

Raw material for coked and graphatised materials are solid powder like carbons e.g. cokes, soot, graphite's etc. of defined grain size. Pitch and artificial resin are used as binding materials.

6.4 Production

The manufacturing process of carbon products is similar to that of ceramic products.
The raw materials coke, graphite and or carbon black (soot) etc. are prepared in crushers, mills and screens.

Then mixed with liquid or solid binding materials, such as tar or artificial resins according to formulation, under temperature.
The grain size and grain distribution of the prepared solids are part of the formulation. With carbons, which are used for the production of tribologically used machine elements, 85% of the grain sizes are smaller 40 μm.
Thus a homogenous material will be achieved even with totally different starting materials. The cold and brittle mixture is then ground again to the defined grain size and cold pressed afterwards.
The mixture can undergo different forming processes according to the desired properties of the end product. It is to differentiate between extrusion, transfer and isostatic pressing. The pressure required is between 800 and 2000 bar.

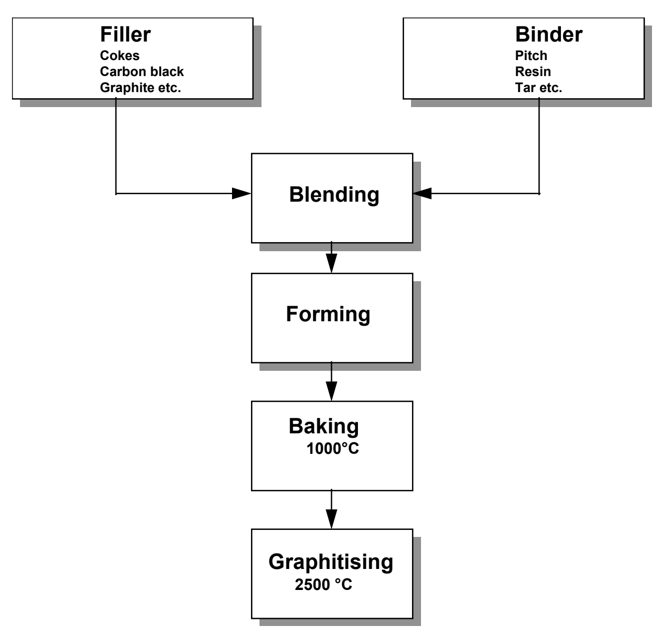


Diagram of carbon production

The production of machine elements from carbon transfer pressing is the most common. The forming procedure is determined by the required quantities, that means large quantities are pressed to size whereas small quantities are conventionally produced from over-sized semi finished products.

Mass production parts normally applied in areas with a low range of loads (stress and strain) e.g. P x V 10 MPa m/s, machined parts for higher range of loads P x V 50 MPa m/s.
With the pressing procedure it is known that the alignment of the graphite laminates is responsible for the good sliding ability of carbon graphite.
The Green Products (unbaked blanks) generated by pressing are then passed on to the next stage which is baking. The means and methods of the baking process, temperature gradient and baking temperature, all depend on the desired physical properties required.

Typical temperatures are in the range of approx 1000°C . Temperature gradients can vary between 0,5°C/hr and 20°C/hr. During the baking process the binding agent in the Pyrolytic converts to pure carbon. The remaining Pyrolytic gases diffuse out of the body leaving a high volume of pours some of which depending on the application can be reduced following one or more impregnation stages.
This process also involves shrinking.
Baking products which have coke or black carbon (soot) fillers at a temperature of 1000°C produce products known as carbon graphite's. Products which have a high content of graphite filler are termed graphite carbons. Electro graphite's are produced by baking at temperatures of 2500°C.

6.5 Properties

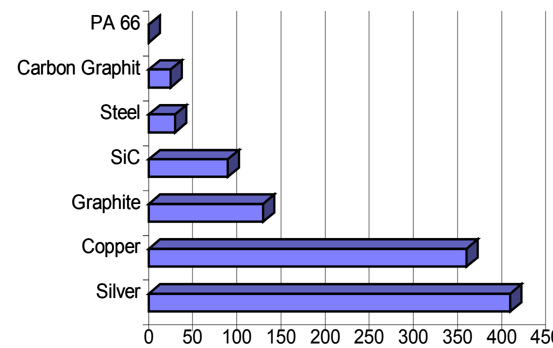
Property	Carbon (100%)	Carbon Graphite (70%-30%)	Graphite-Carbon (70%-30%)	Graphite (100%)
Density (g/cm³)	1,7	1,72	1;75	1,8
Hardness scleroscope	100	85	65	40
Compressive Strength (MPa)	300	208	145	55
Flexural Strength (MPa)	62	62	52	28
Modulus of elasticity (GPa)	21	17	14	10
Thermal conductivity (W/m x K)	5	9	12	85
Temperature limit Air °C	320	320	320	450

Typical data for carbon carbon/graphite, graphite/carbon and graphite

Along with properties such as electrical conductivity and sliding capabilities carbon products possess other extraordinary characteristics which are listed in the following:

Thermal Conductivity

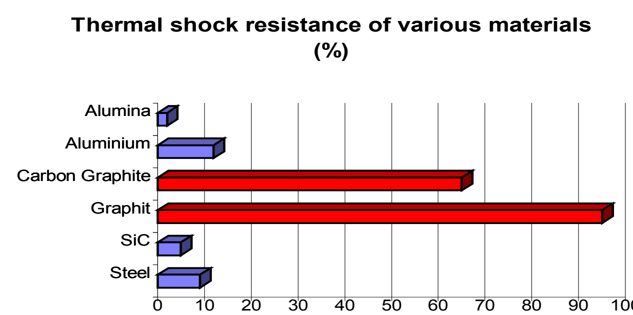
Thermal conductivity plays a major role with materials which have high tribological demands, it has a major influence on temperature at the area of contact. E.g. Heavy duty seals or seals which are working in the proximity of the mediums boiling point, where the temperature difference influences the life-span and functional ability of the seal. For these reasons materials with good thermal conductivity properties are preferred.



Thermal conductivity of various materials.

Thermal shock resistance

From all known materials graphite shows the highest thermal shock resistance.



Thermal shock resistance of various materials

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Chemical Compatibility

The most distinguishing feature of carbon is its chemical resistance against acid, alkaline and practically all organic substances. This makes carbon the ideal material in for example axial seal rings which as a sealing element is preferred in the chemical industry, as it can be used to seal all chemicals. To show the chemical resistance of Morganites carbon products at various temperatures a table has been produced, an excerpt of which can be seen below:

Medium		Temperature °C	Concentration %	ohne	Resin	Antimon	Whitemetals	Leadbrass	Lead	Copper
Acetaldehyd	fl			●	●	●	●	●	●	●
Acetamid	f			●	●	●	●	●	●	●
Acetanilid	f			●	●	●	●	●	●	●
Acetessigsäure-ethylester	fl			●	●	●	●	●	●	●
Aceton	fl	56	100	●	●	●	●	●	●	●
Acetonitril	fl			●	●	●	●	●	●	●
Acetophenon	fl			●	●	●	●	●	●	●
Acetylaceton	fl			●	●	●	●	●	●	●
Acetylchlorid	fl			●	●	●	●	●	●	●
Acetylen	g			●	●	●	●	●	●	●
Acrolein	fl			●	●	●	●	●	●	●
Acrylnitril	fl			●	●	●	●	●	●	●
Adipinsäure	f			●	●	●	●	●	●	●
Allylaceton	fl			●	●	●	●	●	●	●
Allylalkohol	fl			●	●	●	●	●	●	●
Allylamin	fl			●	●	●	●	●	●	●

Section of chemical compatability chart

Temperature Stability

Carbon has high temperature stability especially in inert atmospheric conditions. Carbon has extraordinary properties with increasing temperatures 1000°C to 2500°C where it experiences increases in stability.

The following table gives an introduction of general application temperature limits.

Medium	Temperature - Limits
Air	420 - 460°C (520 - 569 °C pure Graphite)
Steam	ca. 700 °C
CO_2	900°C

Temperature application limits for carbon

Other properties

Apart from the above mentioned properties there are some other special characteristics which the designers of machines and equipment must be aware of. The following table shows some of the positive and negative characteristics of carbon.

positive features	negative features
Stability even at high temperatures	low tensile strength
Physiological inert	limited machining methods (cutting, bending, forging)
environmentally friendly, easily disposed of when no dangerous impregnations are present	not blister resistant
no swelling properties	orientated structure except isostatic pressed material
high stability properties	high energy required in productions process
relatively high wear strength	looses its relatively high wear strength in heavy duty working conditions (vacuum etc.)
can be applied in all friction conditions such as dry and wet running	low elasticity
high compressive strength	brittle
no creeping effects	cannot be produced in long lengths (except extruded blanks)
free for use in food industry	requires special construction directives
no melting point	
electrically conductive	
no scouring properties	
not self igniting	
insoluble	
one of the few materials which loses non of it properties in atomic radiation conditions	
Has the ability to form a transfer film	
cheap	
low thermal expansion	
relative low weight	
not weldable	

Properties of carbon

Gliding ability

The special crystal structures in form of a hexagonically layered lattice is the reason for the distinguished sliding ability. Bragg already assumed in 1928 that this is due to the easy fissionability of the graphite lattice between the base levels.

This quality is easily noticeable while writing with a graphite topped pencil.

These planes levels can be easily moved through the minor van der Waalsche force of attraction; which means the bonding force between molecular layers is relatively small while it is high within the planes.

But this is not the only reason for the extraordinarily good sliding behaviour of graphite. Dobson (1935) and Savage (1945) noticed that the excellent anti friction properties only occur in the presence of water or other vapour. The friction or wear rates rise drastically in a vacuum.

In every normal condition foreign atoms are present (humidity, water etc.) trapped between layers reducing forces and thus allowing easier sliding. When the foreign atoms are removed the sliding qualities decrease.

In order to guarantee the excellent sliding quality of graphite even during the absence of foreign atoms especially water, a procedure was developed during recent years by the carbon industry, respectively substances added to the mixtures during the manufacturing process which take over the water functions.

Graphite materials which were originally used for the tribological systems are not suitable for today's strain in usage. The reason is that during long running in times a thick, dark graphite film forms on the running partner. This leads to high friction that can cause distruction of the friction system.

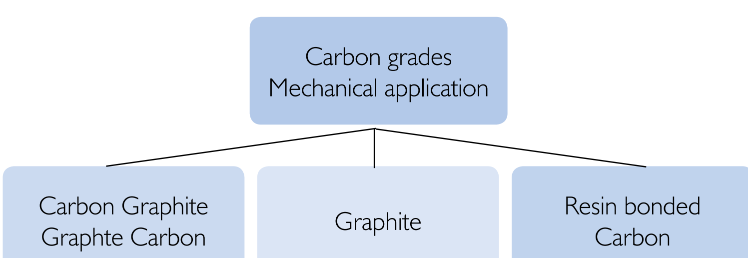
Carbon material, such as that produced for mechanical applications by Morganite, differ from the ideal graphite crystal.

The carbon material development during the last decade was aimed at developing a mixture between the well lubricating graphite molecule and other forms of carbon, e.g. the very hard diamond. Goal of the development was the permanent rubbing off of the transfer film built up on the gliding partner to be kept at the lowest level; similar to an oil film which is just thick enough so the rigid bodies don't touch.

Further information about the complex area of film forming are explained in the chapter "Transferfilm".

Types of Carbon

From the great variety of carbon, 3 main groups are used in the area of machine elements:



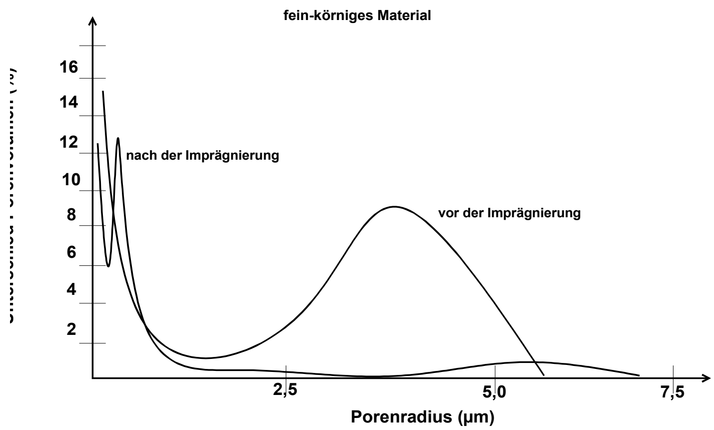
1. carbon graphite
2. graphite
3. resin bonded graphite filled grades

The first two carbon types can be impregnated with different mediums because of the pores created during the baking process. Aims of the partly excessive treatment is the improvement of the physical and technical data of the base grade.

The important impregnation mediums are:

- synthetic resins
- Babbitt metals
- antimony
- inorganic substances

Every one of the impregnation materials has a direct effect on the triblogical characteristics of carbon.



Change of radius of pores

Many of the application cases confirm that impregnation has a 50% share in the successful application of carbon grade.

Factors effecting the tribological characteristics of carbon grades.

The selection of a suitable carbon sliding material is carried out mainly according to the application conditions.

The development or optimisation of such tribomaterals takes a lot of experience and often years of intensive research and endless tests. Within certain limits one is able to produce a carbon body meeting the requirements.

The amount of parameters that influence the running characteristics of carbon grades is shown with the example of impregnated carbon-graphite.

„Factures influencing the tribological properties of carbon grades"

It reflects the factors which have to be considered by research and development departments. Apart from that, other aspects have to be considered:

- economic machine ability
- low cost production processes
- energy saving handling methods

The factors “raw material” on the running characteristics of carbon grade are discussed further.
As already hinted at in the chapter “sliding characteristics”, a graphite transfer film is created on the counter face material whose creation and control is mainly influenced by the raw materials selected in the base formulation.

Transfer film

Carbon is considered among the tribologically used ceramic materials to be the material with the best abilities to form a surface (protection layer) transfer film. The following chart gives a view of these qualities with different materials.

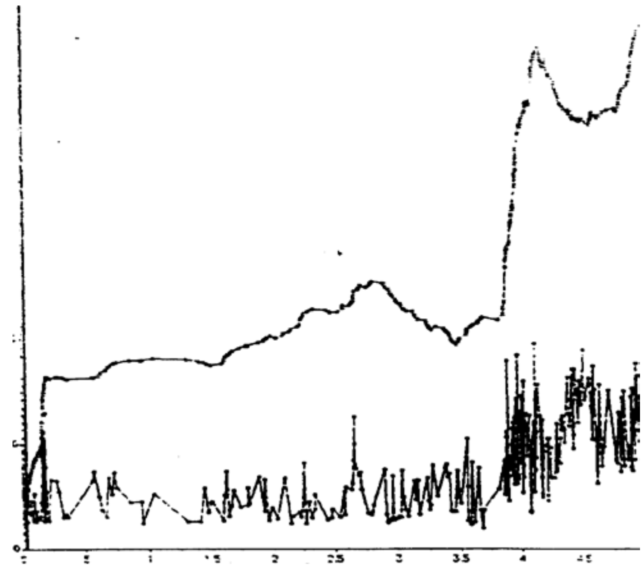
The formation of a protecting transfer film :	
given from	not given from
Carbon - Graphite	Al_2O_3
SiC	Zirkonia (Zirkonoxid)
Silicon-Nitride	

Film forming properties of various cerarmic materials

The balance between the film former and the film controller in modern tribologically heavy duty carbon materials is mainly controlled by the raw materials and their special treatment. The development of those materials contain decades of experience and thousands of hours of testing.
An optimised carbon grade with a fine choice of raw material and blending, should form a cohesive uniform transferfilm in a short period of time with a minimal chance of film collapse.

What occurs in a sealing contact?

After the build up of the tribosystem there is no carbon on the counter face partner. Only after a short running in time graphite particles are worn away from the counterface material’s roughness peaks. These graphite and wear debris become imbedded in the indents of the counter partner and the carbon materials. This procedure is connected to a temporary increase of the friction moment and temperature at the contact surface.
A large ultra flat contact surface with a high supporting surface is created. This can be positive or negative. (Clark and Lancaster investigated in 1963 that the wear of carbon materials is due to local surface fatigue. This wear can be reduced by an increased supporting surface or the big contact area which is produced by the carbon film. The transfer film protects both gliding surfaces from wear. Film fatigues occurs, tears away and forms again. The procedure of periodically occurring film forming and its breaking down can be proven with torque and temperature measurement.
The stable function of the transfer film depends on a great amount of factors that can’t be explained in detail at this stage. E.g. the tribosystem can not only break down due to incorrect carbon grade but also because of operating conditions which are too excessive. If the sliding speed and or the load are too high the tribosystem can go from a stable state to a temporarily state of increased friction and even to an unstable state.



Friction - Temperature / Time

Summary of the process involved in film formation

The film formation

- Initially no Transfer film is present which results in higher friction and wear rates.
- Wear debris form a uniform transfer film between gliding surfaces.
- Friction and wear are reduced and the base material is effectively protected by the transfer film
- All wear debris become either imbedded in the transfer film or become expelled from the interface
- A transient event disturbs the transfer film
- At this point the procedures repeats it`s self over again

Relative carbon grade applications

One can deduct from these facts that the right balance between formation of transfer film and control requires a multitude of different carbon types for different applications to achieve optimal results. It used to be possible to compare carbon grades of other producers by means of equivalent lists. Today a suitable grade is determined following detailed descriptions of the operating conditions.

Operating conditions

The sales engineer must try to obtain as much information possible from the applications adviser in the factory relating to the application case. Information about a successful unsuccessful

performance of competitors grades can be used additionally as important facts and avoidance of unnecessary tests.
The following questionnaire example for a bearing lists some of the most important information.
During the past years there were only a few standard types offered by the carbon producers that covered the entire application spectrum. Today there is a great variety of grades individually adjusted for each friction system.
Since that development trend was and is mandatory for modern high performance carbon, it will be demonstrated with three typical applications:

Examples of different cases

Case 1
Vanes for vacuum pumps

(intermediate performance pump; industrial application)

Operating conditions:

- Dry running (in direction of vacuum)
- high temperatures
- strong interference from external forces

The use of a Electrographite with dry running supplement is recommended. The material should not be too soft because of a high friction strength and also has to be of high mechanical strength. The history of carbon vanes for vacuum pumps shows that the development of machines is in line with the development of the vane material.

The vane is an extraordinary element in the great variety of carbon for mechanical applications. That is due to the collective demands as well as the required sliding characteristics under certain conditions. That is why there is a chapter dedicated to this machine part in the appendix. It gives the interested reader the first insight into the complex matter of the simple black discs.

Case 2
Mechanical seal for heavy duty seal

Operating conditions

- guaranteed wet running
- high specific loading
- high rubbing speed
- great variety of different mediums
- different counterface partners

A graphite carbon can be suggested for this application with the appropriate impregnation.
A material with higher strength and hardness is required. Only 20 years ago, one didn't believe that such a carbon material, which is constantly used today, would be applicable as a tribological material. Similar to the vane materials, development alongside the development of counter face material.

Case 3
Bearing for dry running

Operating conditions

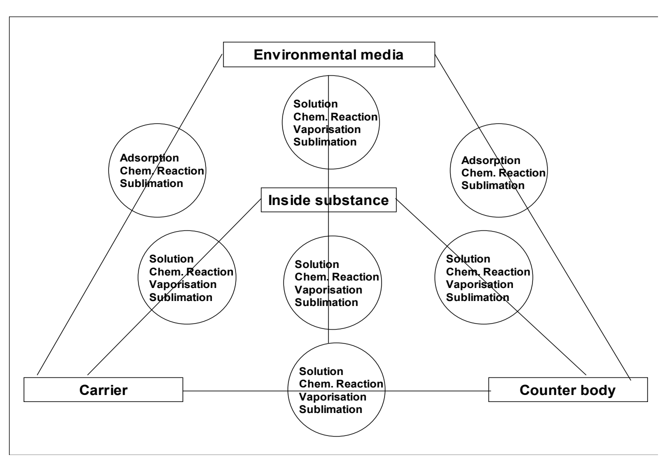
- dry running
- partly high specific strain
- high temperature
- low rubbing speed

The use of elctro graphite with the required impregnation for this temperature can be suggested. A material with high compressive strenght and oxidation resistance is demanded.

Conclusion

This multitude of characteristics of the element carbon, especially its extraordinary tribological characteristic lead to its use in an extremely wide area.
Carbon and graphite form a group of materials with considerable technical possibilities. Therefore considerable efforts are made in all industrialised countries to extend the scientific base and to improve the production of carbon with its endless varity of microstructures.
Apart from the constant mandatory improvements of the friction strength, a number of recent developments are listed:

- optimization of PTS production (especially possible with the new generation of computer controlled presses)
- -reduction of start-up torque with sealrings through optmisation of formulation and surface quality
- Application: mechancal seals in Dish washers, washing machines and automotiv water pumps
- further development in the area of binderless graphites.



MORGAN ADVANCED MATERIALS

MANUFACTURING LOCATIONS

Our manufacturing sites are ISO 9001 and where applicable ISO 13485 certified

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