DLR_School_Lab Köln

Material sciences

31st May 1811. Ludwig Albrecht Berblinger is standing on the Eagle's Bastion on the wall surrounding Ulm. He is wearing wings and wants to show his royal spectators that he really can fly with them. His attempt fails: The "tailor of Ulm" lands in the Danube, accompanied by the ridicule of his audience. 90 years later, Otto von Lilienthal manages a few successful flights with his glider before he crashes and dies. Today's hang gliders need not worry about their aircraft breaking apart as modern materials are a lot lighter and sturdier than wood and canvas.

The right materials in the right place

When implementing a technical idea, choosing the right material is extremely important. Particularly in aviation and aeronautics, as the materials are exposed to very challenging environments. They need to be as light as possible while retaining their hardness. They are required to withstand very high temperatures and continue to be completely safe after many hours of use.

The Airbus A 380 is 73 m long and has a wing span of almost 80 m – making it much larger than a jumbo jet. The only way such an unusually large and heavy aircraft (560t start weight) will stay airborne, is if it is built using the lightest and most stable materials possible.

When re-entering the Earth's atmosphere, heat shields have to be able to withstand temperatures of up to 5,000°C. That is as hot as the surface temperature of the Sun!

Where do we find the right materials?

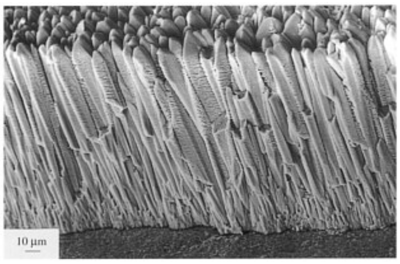
We have a wealth of materials on Earth that are well suited to construction. There are the natural building materials such as wood or clay. Aerospace technology mostly uses plastics, as well as metal or ceramic materials. Metals are hardly ever used in their pure form, but rather as alloys. This increases their performance. For example, iron is made into stainless steel by controlling the carbon concentration and adding the right amounts of chrome and nickel.

Some parts of aeroplanes that are required to withstand a lot of strain are made of steel. For the most part, planes are made of light metals such as aluminium and titanium alloys and increasingly of fibre-reinforced plastics. It is a constructor's job to choose the most suitable material or material combination. On the one hand, it is important to consider and guarantee the passengers' safety, on the other to avoid excessive production and operational costs. This can only be achieved through detailed knowledge of material characteristics.

The combination is key

Material scientists do not only test a material's properties, they also develop new materials with improved characteristics.

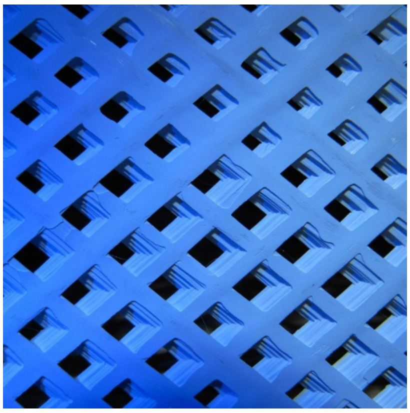
Wherever a material is needed that can withstand high temperatures, for example in the combustion chambers of gas turbines, ceramics are used. But you might already have noticed this while drying the dishes – ceramics are very hard, but also very brittle and they break easily.



Ceramic coating on a compressor blade

Weave, glue, sort, cast…

If you change the structure of ceramics or combine them with metals, they then withstand much greater strains. The DLR's Institute of Materials Research has developed a new, light and mechanically resistant material made of ceramic fibres. With the help of computer controlling, the fibres are woven over each other into layers and then glued together (more accurately: sintered together). WHIPOX™ is able to withstand heat in the same way as conventional ceramics can and could be used to line combustion chambers in aeroplanes or rockets.



Ceramic fibres: detail of a WHIPOX™ plate

It is not only the aerospace industry that profits from materials research. The automotive and construction industries are also always on the lookout for new materials that will enable the next generation of machines and buildings. A lot of "by-products" of materials research have been incorporated into everyday life, for example reinforced concrete, which is used for constructing bridges and houses. Materials research findings are also used in sports and other recreational areas in order to break world records.

Material properties

Anybody interested in constructing, developing and implementing new technological ideas and devices has to know a lot about characteristics of materials. We will discuss some of these properties in more detail.

> Two substances that have the same weight may take up different amounts of space: They differ with respect to density.

> Changes in temperature can lead to changes in length and volume.

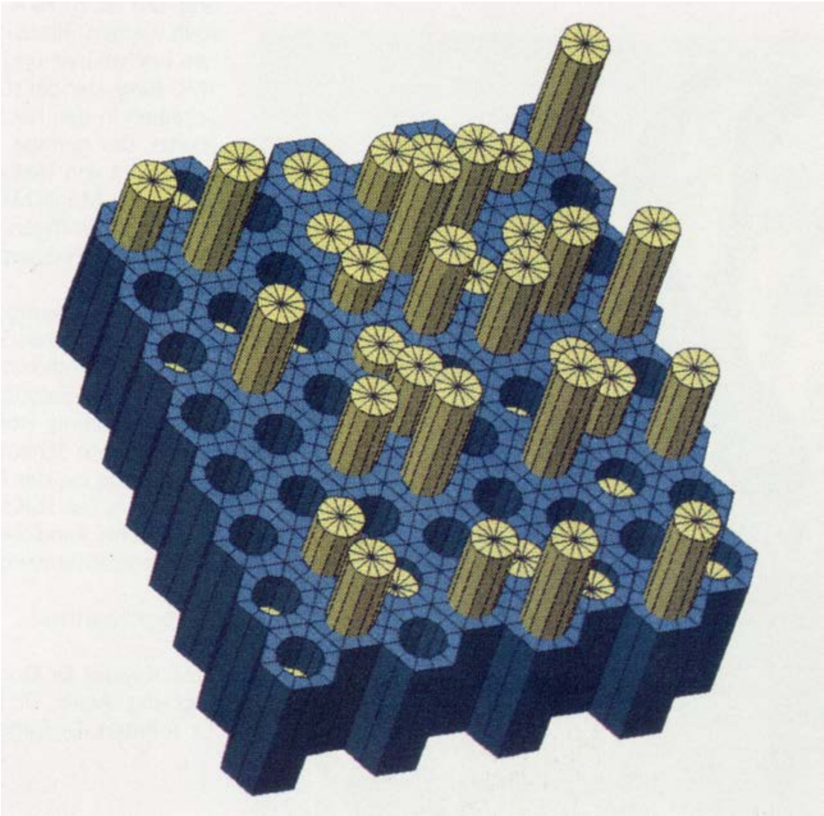
> Different materials can wear out due to heat. They also have different melting points.

> Metal is very conductive to heat, whereas ceramic behaves differently. Air is bad at conducting heat and therefore makes a good isolator.

> Which materials are conductive to electricity?

> The hardness of a material often determines its usage, for example drills that are developed for extreme conditions or scratch-proof surfaces.

> Try not to mix up hardness and solidity! As you will see, some materials are hard, yet not mechanically resistant.



Composite matrix of titanium and ceramic: Embedding ceramic fibres in titanium increases the solidity of, for example, turbine blades.

What holds the world together?

Why do materials have such different properties? Material scientists research the connection between characteristics and structure of materials.

Solid bodies are made of particles that are close together and occupy a defined position. They may only circles around this position, whereas in liquids or gases, particles can move freely against or around each other.

In chemistry, we differentiate between three different types of bonds

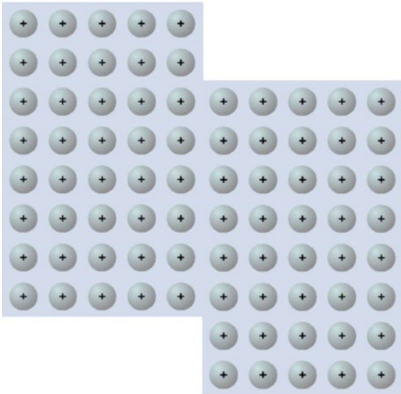
> **Ionic bonds:** electrically charged particles are bound together due to electrostatic forces

> **Metallic bonds:** omnidirectional bonding and delocalised electrons ("electron gas")

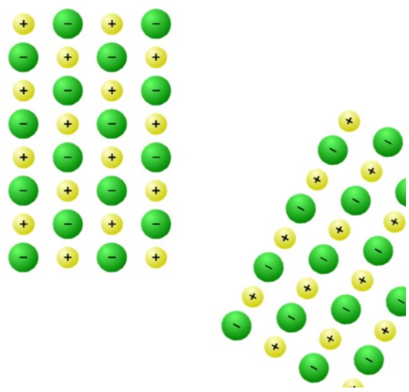
> **Covalent bonds:** Electron pairs are shared between atoms

Imagine a substance as a system of spheres that are in contact with one another. There are basically two ways in which these can be arranged in a three-dimensional space: crystalline or amorphous

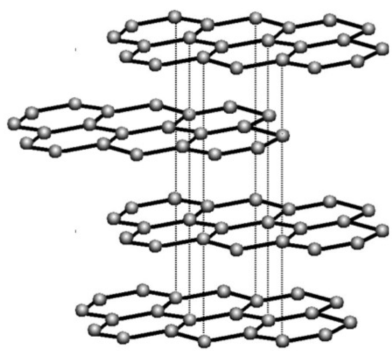
Order can be useful…



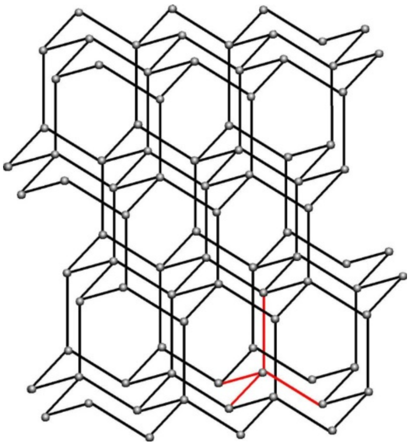
Metallic bonds (e.g. iron): The atoms can be moved across each other. This is why metals are malleable.



Ionic bonds (e.g. salt or ceramic): breaks under strain. These materials are very hard, but brittle.



Covalent bonds (e.g. graphite): Atoms within one layer are bonded together and cannot be separated easily. Different layers can however be moved across each other.



Covalent bonds (e.g. diamonds): A lot of energy is needed to move the atoms; this material is extremely hard.

…as can chaos

Plastics (for example polyethylene, PVC or silicone) are made of polymers, which are chains of molecules. They are usually wrapped around each other in a completely unsystematic manner ("spaghetti conformation"). This means they can be stretched and are elastic. Glass is also an amorphous substance.

Polymer chains when slackened and tautened

The experiments

We will compare the characteristics of metals, ceramics and plastics. We will carry out experiments to test the properties mentioned above and to ascertain the possible applications for each material.

> Liquid nitrogen (-196°C) will be used to reproduce the variations in temperature that occur in aircraft. (On a normal passenger flight at an altitude of 10.000 m (~33000 feet), the outside temperature drops to about -50°C.)

> With the help of a drop apparatus, we can define the strain to be put on our samples and test their resistance to deformation or their behaviour at rupture.

> We will use a circuit analyser to determine the electric conductivity in relation to temperature.

> What is harder? What will scratch which surface? The Mohs scale of mineral hardness tests materials from talc to diamonds.

> How can we combine the various characteristics of different materials? We will look at modern composites.

Literature:

Hausmann, J.M.: Modellierung und Optimierung faserverstärkter Titanlegierungen. Tenea-Verlag, Berlin, (2003), 132 S., ISBN 3-86504-007-1

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Peters, M. und Kaysser, W. A. (Hrsg.): Advanced Aerospace Materials. DGLR-Bericht 2001-02, 2001, ISBN 3-932182-16-2

Web pages:

http://www.dlr.de/wf/

DLR at a glance

DLR is the national aeronautics and space research centre of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport, digitalisation and security is integrated into national and international cooperative ventures. In addition to its own research, as Germany's space agency, DLR has been given responsibility by the federal government for the planning and implementation of the German space programme. DLR is also the umbrella organisation for the nation's largest project management agency.

DLR has approximately 8000 employees at 20 locations in Germany: Cologne (headquarters), Augsburg, Berlin, Bonn, Braunschweig, Bremen, Bremerhaven, Dresden, Goettingen, Hamburg, Jena, Juelich, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, Oldenburg, Stade, Stuttgart, Trauen, and Weilheim. DLR also has offices in Brussels, Paris, Tokyo and Washington D.C.

DLR Cologne

Aviation, space travel, transportation, energy and safety are the research areas pursued in the nine research facilities at DLR Cologne. The basis of the research and development carried out on site are the large testing facilities such as wind tunnels, turbine and materials test benches and a high-flux density solar furnace. The 55 hectare/ 136 acre site is home not only to the research and administrative facilities of the DLR, but also to the European Space Agency's (ESA) European Astronaut Centre (EAC). The DLR has around 1400 employees in Cologne.

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About the experiment:

Recommended for grade(s): 4 to 9
Group size: 5 to 6
Duration: 50 minutes
Subject matter:
Physics
Chemistry