RADIATION CROSSLINKING:
FROM PLASTIC TO HIGH-PERFORMANCE MATERIAL

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FROM PLASTIC TO HIGH-PERFORMANCE MATERIAL

Plastics are light – and have immense potential, particularly in lightweight construction, due to the combination of low weight, good performance properties and excellent shapeability. Through the process known as radiation crosslinking, which changes the physical properties of the material, this potential is significantly extended. The application possibilities are huge for these plastics refined by means of beta and gamma rays, especially in view of new mobility concepts.

Lightweight construction is one of the best ways to lower fuel or energy consumption of vehicles. At the same time, plastics are a tried and tested resource and have been used increasingly for years: According to the business consultancy Frost and Sullivan, the share of plastics per car increased from about 100 kilograms to approximately 115 kilograms between 2009 and 2019.[1]

1. https://www.automobil-industrie.vogel.de/fachmesse-k-alles-zu-kunststoffen-a-869585/

However, high-performance plastics are expensive and injection moulding of the corresponding moulded parts places high demands on machines, tools and processing. By contrast, inexpensive commodity plastics and technical plastics are often not able to meet the necessary requirements. For example, this applies to temperatures or extreme environmental conditions – through radiation crosslinking, they can, however, be enhanced for the appropriate applications.

Radiation crosslinking is the process suited for this. In the automotive industry, this technique is increasingly used to modify the properties of plastic components for certain applications, for example, in terms of their thermal and chemical resistance for applications in the engine compartment, drive train and electrical systems.

In simplified terms, crosslinking is a physical process that changes the mechanical, thermal and chemical properties of commodity plastics and technical plastics with the help of beta and gamma rays. Through this process, the materials come close to the qualities of high-performance plastics and are often able to replace them.

The properties of the treated plastic components change significantly:

→ Improved strength and creep properties

→ Higher heat deflection temperature and dimensional stability

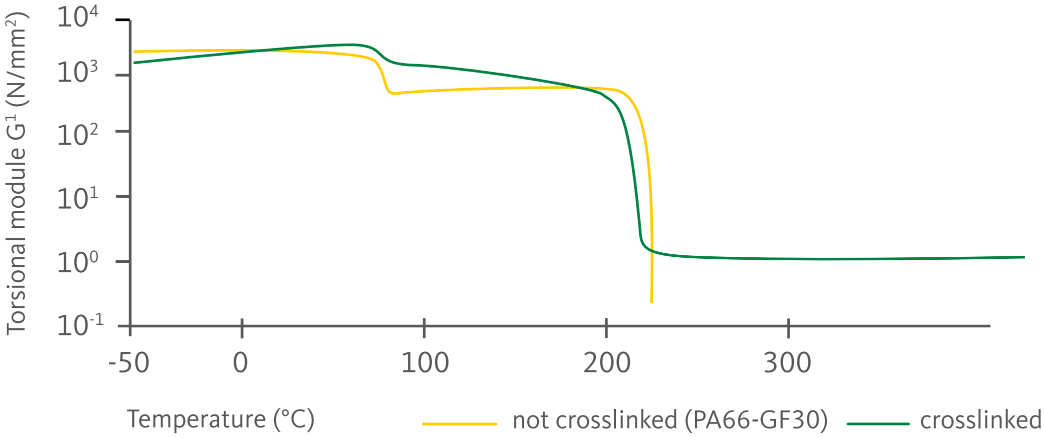
→ Improved resistance to aging

→ Reduced swelling and improved stress crack resistance

→ Improved compression set

→ Improved tribological properties, in particular friction and wear

Heat deflection temperature of radiation crosslinked PA66



WHERE CAN IRRADIATED PLASTIC COMPONENTS BE USED?

The modified material properties and the better durability of irradiated products open a broad field of potential applications: For instance, metals in functional components can be replaced by crosslinked injection moulded components out of plastic (e.g. PA or PBT).

→ **Metal replacement / lightweight construction**
Fastening elements such as bolts and nuts, holders or clips out of metal can be substituted by radiation crosslinked polyamide. The large number of assembled parts in and on the vehicle and a possible reduction in weight by a factor >5 offer enormous savings potential in terms of total weight and manufacturing costs (metalworking vs. injection moulding).

→ **LED technology**
The temperature development in LED headlights is higher than in conventional headlight systems due to the compact design and power electronics. The requirements profile for

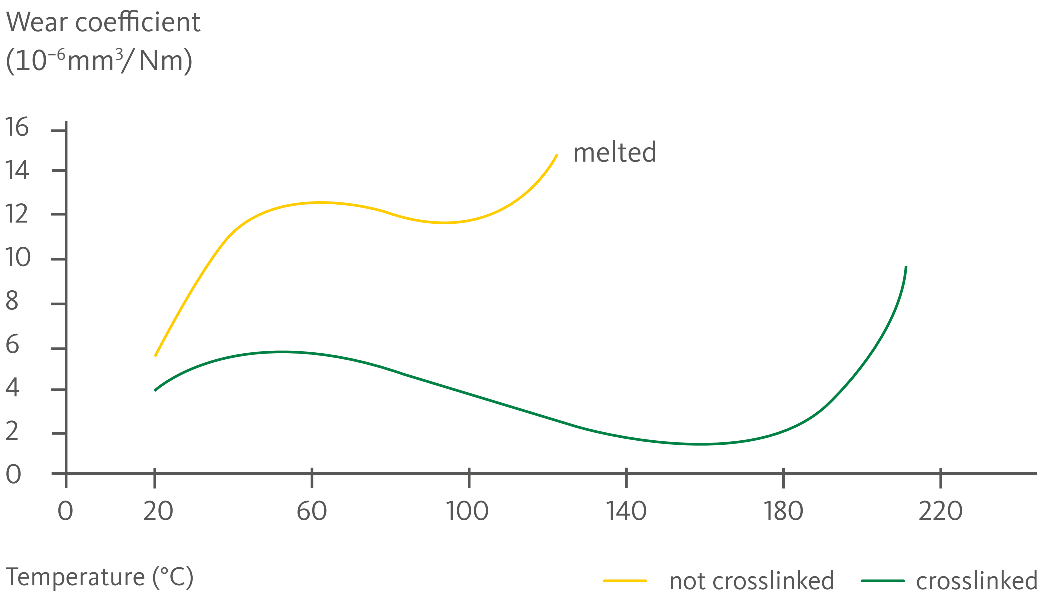
the housing components and especially for the reflectors changes significantly and can be fulfilled using radiation crosslinking.

→ **Vehicle power supply**
In some cases, electric vehicles are equipped with batteries of over 800 volts that can be charged at quick charging stations with up to 350 kilowatts. If direct current is used, the current can reach up to 500 amperes. Likewise, the energy transfer from the battery to the drive requires cable systems with large conductor cross-sections and temperature-resistant insulation materials. New demands on the materials to be used are arising in connection with these new electrical system architectures.

→ **Autonomous driving**
Assistance systems and autonomous systems are the basis for automated driving functions. To this end, data are essential which are supplied by a number of sensors. They are connected by way of cables, binders and connectors which often have to stand up to harsh conditions. Actuators carry out the mechanical functions: For example, in lane control systems, in the throttle control for adaptive cruise controls, in electronic braking systems, or automatic transmissions. The motors have to be compact, lightweight, quiet and durable, or more specifically, maintenance-free.

The requirements for materials used in transmissions and sliding components, such as gear wheels, bearing and slide bushings are changing considerably. Radiation crosslinked components can be an economical alternative here as opposed to metal materials or expensive polymers (PEEK, PAI, etc.).

Effect of ambient temperature on wear coefficients

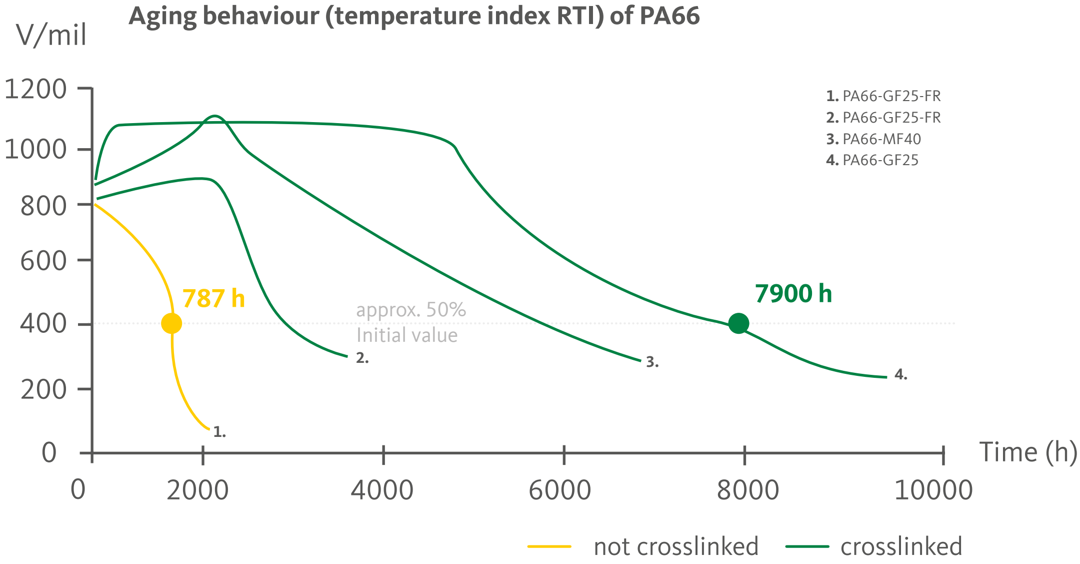


Polyamide not crosslinked, and exposed to friction has an application limit of 120 °Celsius. Radiation crosslinking (green curve) prevents melting of the material and increases the permanent operating temperature by up to 100 °Celsius with a simultaneously reduced wear rate.

CROSSLINKED COMPONENTS IN SERIES PRODUCTION

Crosslinked plastics are already being used in series production by well-known automobile manufacturers. Areas of application include, for example, blow-by pipes in combustion engines that drain off complex mixtures of oil, exhaust gas, unburnt fuel and water from the crankcase. The requirements regarding temperature and media resistance are accordingly high. In the process, polyamide is used (PA6, PA66). Other examples are pressure tanks from PE, axle boots, bellows, air and media-carrying components, holders and fastening clips from 2-component injection-moulded parts, or slide and roller bearings, where the improved tribological properties lead to low abrasion and frictional wear and reduced creep tendency.

Aging behaviour (temperature index RTI) of PA66



The test describes the aging behaviour of a plastic after storage at high temperature. PA66 not crosslinked only has 50% of its electrical insulation properties after about 800 hours. A crosslinked polyamide achieves a tenfold service life.

A test known as the “glow wire test” allows for a relative comparison of the flammability of different materials. In the process, a measurement device presses a glowing wire tip onto the component. Whereas the wire will pierce conventional plastic within seconds, the treated materials withstand the glowing wire.

HOW DOES RADIATION CROSSLINKING WORK?

Energy-rich beta or gamma rays trigger a chemical reaction in the plastic parts resulting in a crosslinking of molecules – comparable to the vulcanisation of rubbers. When the electrons penetrate the matter, this causes excitation within the molecules. As a result, hydrogen atoms are ejected. Individual plastic molecules are chemically bonded with one another and irreversibly crosslinked. New chemical bonds are thus created in the polymer matrix that form a three-dimensional network with improved properties. This process takes place at room temperature. At the same time, the radiation dose determines the properties of the material.

Accordingly, this technique is suited for large-scale production. Since it involves an electrical parameter, the dosage is reproducible.

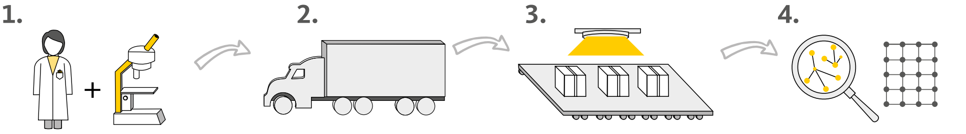
Depending on the energy of the electrons, the components can be irradiated up to several centimetres thickness, also in combination with other materials. The preferred type of radiation is the beta radiation. Contingent on the application, irradiation with gamma rays may be necessary. The potential is huge: In vehicle construction, 100 kilograms of plastic replace about 200 to 300 kilograms of conventional materials and help to save on weight, energy and valuable raw materials.

HOW DO THE PRODUCTION LOGISTICS OF THE PROCESS WORK?

In order to be able to use irradiated parts and components in serial production, the related processes have to take place smoothly and in particular, quickly.

Compared with duroplastics, which often require costly post processing, or high-performance plastics with their difficult processing properties, radiation crosslinking offers tremendous processing benefits at reduced costs. The original processing methods of the raw components are retained and only the finished product is treated, i.e. the production does not have to be adjusted. Radiation crosslinking is the last step after moulding and can be integrated into the production chain as part of the transport to the end user. It is important for all project participants to work together from the start: from the plastics supplier to the manufacturer.

Radiation crosslinking takes place in four steps.



1. Development and parameter selection
2. Delivery of products
3. Irradiation and crosslinking of the products
4. Quality control and dispatch of the finished products

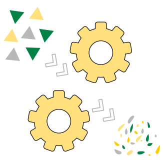
ARE IRRADIATED COMPONENTS DANGEROUS?

For plain physical reasons, the applied radiation sources - electron accelerators up to a maximum energy of 10 MeV and gamma rays emitted by the cobalt isotope 60Co – are not able to generate any radioactivity. Due to their energy, the rays trigger chemical reactions which induce crosslinking. The result is comparable to chemical crosslinking processes; however, radiation crosslinking generates the necessary radicals through the energy of the radiation, thus preventing chemical residue.

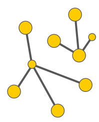
In the facilities themselves, the radiation is completely screened and all processes are fully automated so that radiation exposure of any kind for humans or the environment can be safely ruled out.

WHAT HAPPENS WITH THE CROSSLINKED COMPONENTS AT THE END OF THEIR SERVICE LIFE?

Components crosslinked by radiation are extremely resistant and usable over very long periods. At the end of the service life, three processing options are possible:



Material recycling (physical)



Feedstock recycling (chemical)

Energetic recovery (thermal)

Material recycling produces new plastic components from secondary raw materials. If production residues are homogenous and of one type prior to crosslinking, reuse is possible in the original application under certain conditions.

Homogenous crosslinked plastics can be ground up and added again to primary raw materials as regranulate within specified limits.

These limits depend on the material and the degree of crosslinking and have to be assessed in each individual case. If material recycling does not make sense or is not possible, radiation crosslinked components are fed into feedstock or energy recycling without issue.

WHAT POTENTIAL DOES RADIATION CROSSLINKING HAVE FOR MOBILITY?

Radiation crosslinking using beta and gamma rays optimises the properties of standard and technical plastics. Following irradiation, polymers are mechanically stronger, more resistant to heat and abrasion, and more resilient to chemicals. Thus, they can be used in considerably more applications.

The potential of radiation processed materials has two essential dimensions: an economical and a technological one.

In this way, radiation crosslinked thermoplastics are able to replace high-performance plastics and even metallic materials to a certain degree. While high-performance plastics such as PEEK place special demands on processing, radiation crosslinking makes it possible to continue working with established raw materials and, despite the combined costs for raw materials, irradiation and logistics, to produce less expensively on the whole. In processes involving industrial serial production, irradiated parts and components can fully display their strengths, since the original production process of the raw components can be maintained and only the finished product is treated, i.e. the production does not need to be adjusted. Radiation crosslinking is the last step after moulding and can be integrated in the production chain as part of the transport to the end user.

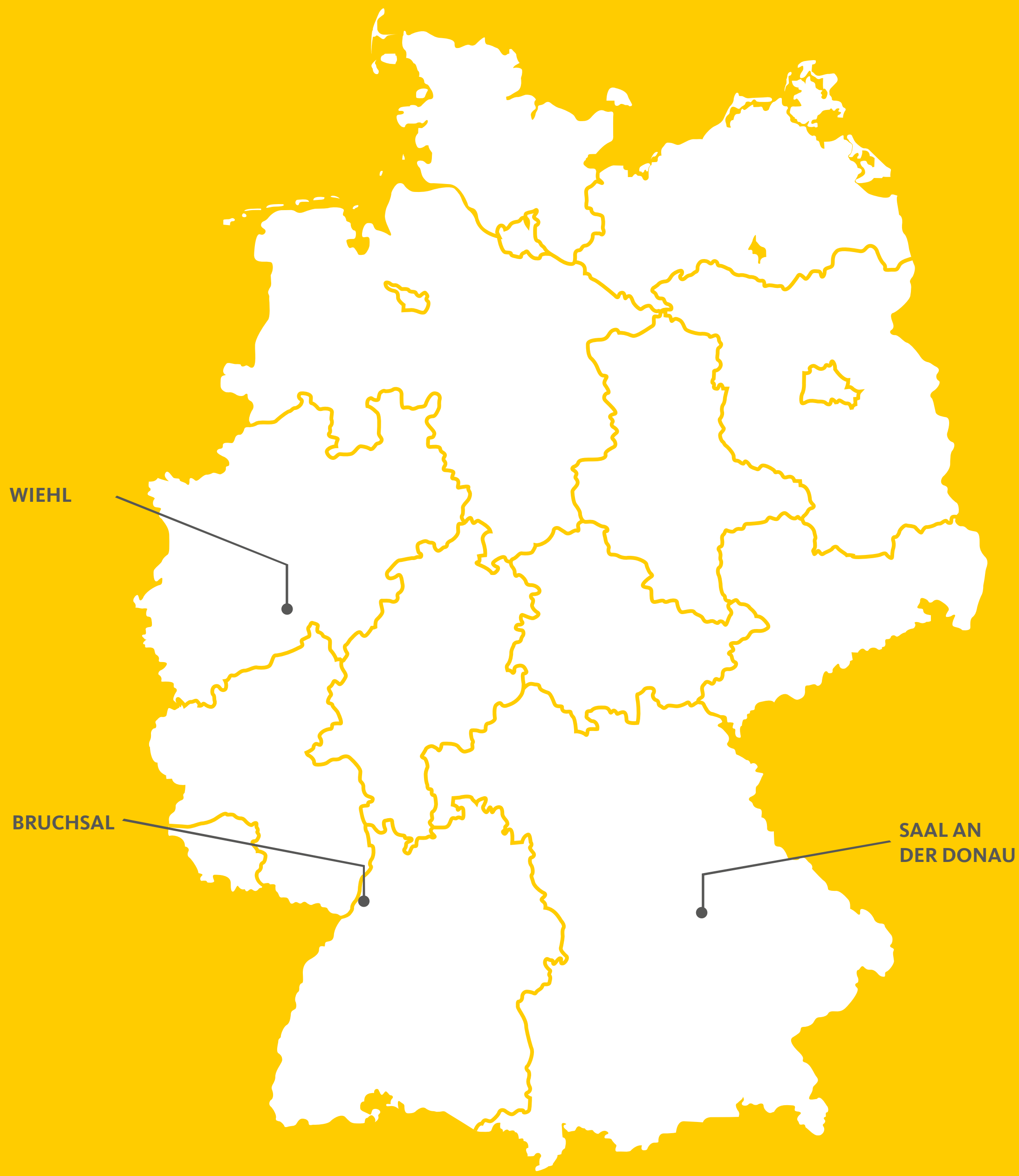
The technology change taking place in the automotive industry opens great opportunities and new potential for the use of radiation crosslinked plastics. The trend towards electromobility entails huge changes and will completely transform the portfolio in the next years. Components and assemblies used up to now will be dispensed with, new ones will be added especially in the area of the drive train as well as in the development of lightweight design. In this context, materials are being scrutinised as new demands are placed on them.

Numerous applications show that radiation crosslinked components out of PBT can be successfully used in current-carrying systems, for example, in connectors, circuit breakers and insulators. Radiation crosslinked thermoplastics can also demonstrate their strengths in fuel cells and in batteries where the materials used are exposed to high thermal loads during charging and discharging, and have to withstand corrosive chemical substances.

The prospect also exists for new applications such as composite materials out of fibre-reinforced materials, which can be optimised technologically through improved fibre-to-matrix connections or crosslinked matrix materials – and this, while keeping weight to a minimum.

At the moment, it is a challenge as well as an opportunity that the requirements for applications in electromobility have not yet been defined and may vary depending on country, manufacturer and supplier. The success of future mobility concepts and new applications in the automotive industry will also depend on jointly developed standards; here it is important to bring together all those involved in the value chain, in particular the materials developers and users, and to analyse the new requirements and contribute the respective expertise to the development processes. And one thing is certain:

The potential of radiation crosslinked plastics is far from being fully realised.



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