APPLICATION INFORMATION

# ADDITIVE SOLUTIONS FOR RECYCLING APPLICATIONS

# Contents

# A new life for recyclates

Thermoplastic materials are in high demand due to their versatility and are used in a wide range of industries and applications worldwide, from automotive and electronic products to construction, film, and packaging industries.

When these products reach their end of use, an increasing proportion of them do not end up in landfills or incinerators, but find their way back via recycling to be used again.

PET bottle recycling is a notable example in recent decades of achieving a very high return rate with a simultaneous high-quality material stream. Ideally, this results in beverage bottles made of 100 % recycled PET.

Environmental and economic interests, regulatory requirements from policy, and public opinion are driving increased interest across industries in recycling plastics and improving sustainability across the board. Subtrends such as source reduction, lightweight applications, biodegradable materials, and less hazardous chemicals are expected to create a greener economy around the recycling market.

For additional information on additives and technical topics, please contact us:
**Thermoplastics.BYK@altana.com**

Suggested additives for the recycling of thermoplastics can be found in the brochure TP-G 2: **Recycling of thermoplastics**

**Note**

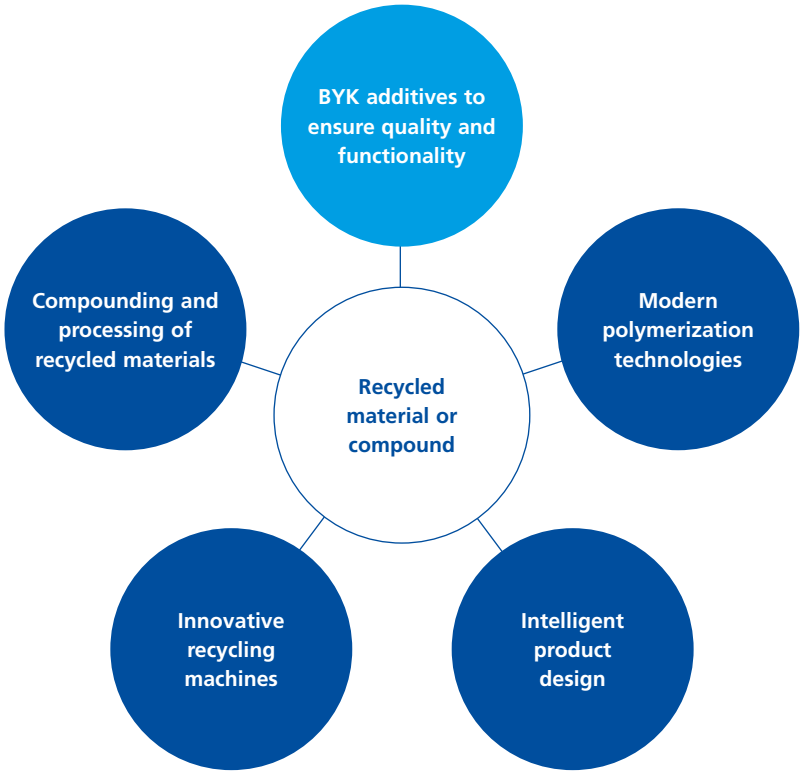
To ensure the best appearance and full functionality, please open in Adobe Acrobat.

# BYK's contribution to efficient recycling of thermoplastics

The requirement to use ever greater quantities of recycled polymers in final formulations and the almost unlimited number of different polymer combinations, fillers, and other ingredients face the industry with a large number of challenges.

Overcoming these challenges requires a whole toolbox and a multi-level approach to achieve the desired properties:

## Toolbox to overcome recycling challenges




G.01

BYK is a leading global supplier of specialty chemicals. The company's innovative additives and differentiated solutions optimize product and material properties as well as production and application processes. The recycling of thermoplastics is also supported by the use of BYK additives.

BYK continuously develops new additives and works together with customers to find new solutions for current and future challenges. Our modern and professionally equipped laboratories make it possible to try out and test the effectiveness in realistic applications.

**Laboratory building**

**Twin-screw extruder (Ø 25 mm, LD 40)**

**Cast-film line**

**Injection molding**


**Material-testing laboratory**

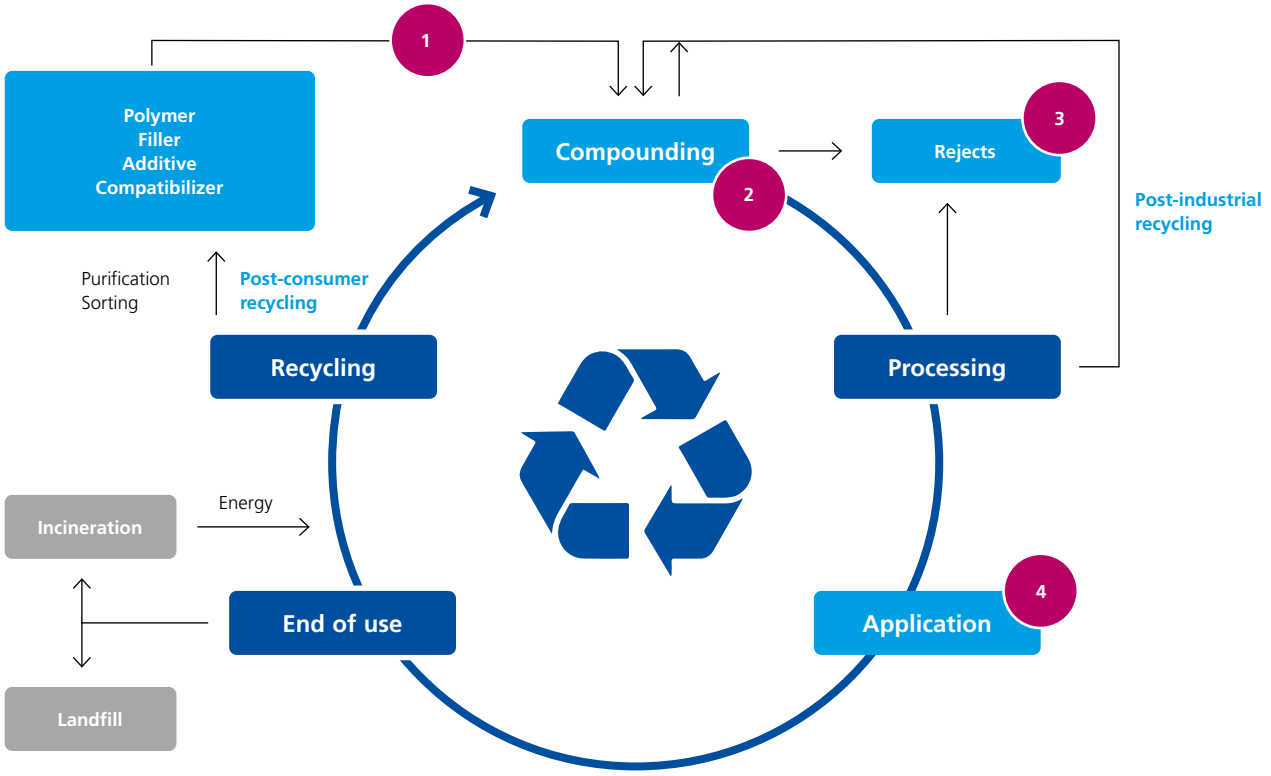
**Burning chamber**

# Restabilization of recycled thermoplastics

At the beginning of the first cycle of use, thermoplastics are equipped with a variety of raw materials and additives to prepare them for their intended use. These include, for example, UV stabilizers or additives to increase mechanical and thermal properties. As the finished parts are used and age, the components lose their effectiveness and are depleted. At the end of use, there are various options:

a. Storage at landfill
b. Incineration for energy production
c. Recycling for reuse of the polymers/polymer blends

## Recycling cycle



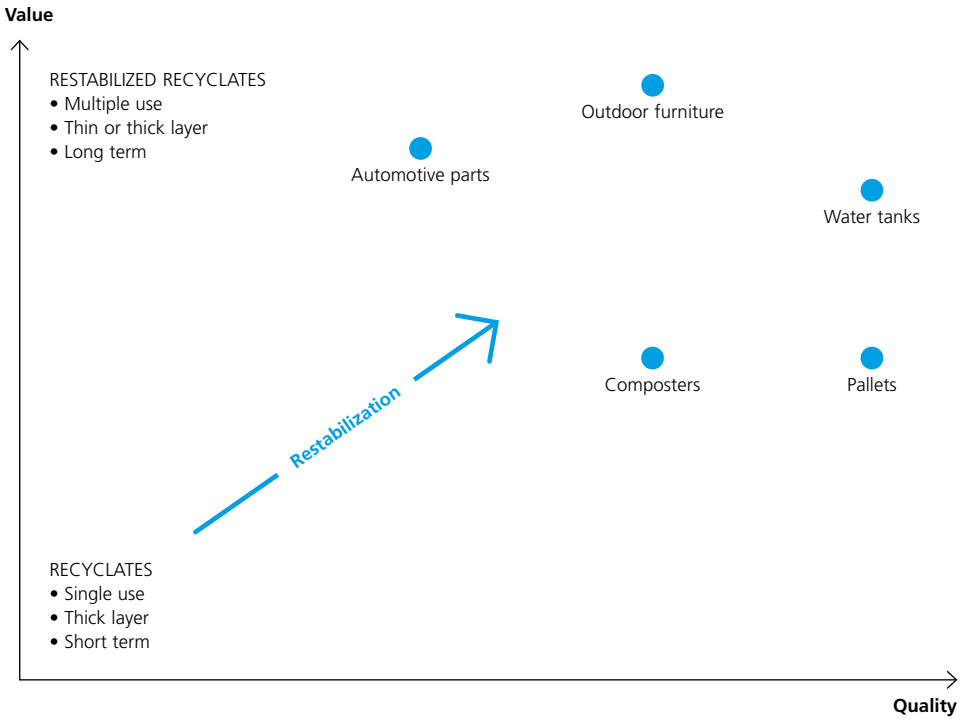

G.02

During reprocessing in the course of recycling, effects previously desired through raw material mixtures may interfere so strongly that reuse is not possible. A typical challenge, for example, is the originally complementary combination of different plastics, such as occurs in multi-layer films. The polymers can only be separated again with great difficulty, often not at all. As a mixture – a polymer blend – they are virtually unusable without compatibilization. In addition, impurities, pigment residues, or filler load, which is now too high or incorrect for further use, can reduce the performance further. The compounds processed directly from the recyclate in this way are often only suitable for the manufacture of low-cost and low-quality products.

The use of BYK additives creates added value throughout the whole recycling value chain. The granulated, non-dusting delivery form of BYK products ensures safe handling and dosing 1. In addition, the improvement in processability enables process optimization, lower lead times 2, and a reduction in rejects 3, while the quality of the component can be significantly increased by reducing odor and increasing strength 4.

BYK offers a variety of products to restabilize the recycled plastics and improve the mechanical properties. Improved mechanical strength and long-term thermal stability while maintaining rheological properties increase the recyclate's potential uses. Thus, the end products can also be used in high-quality applications.

## Use of restabilized recyclates




G.03

## Applications

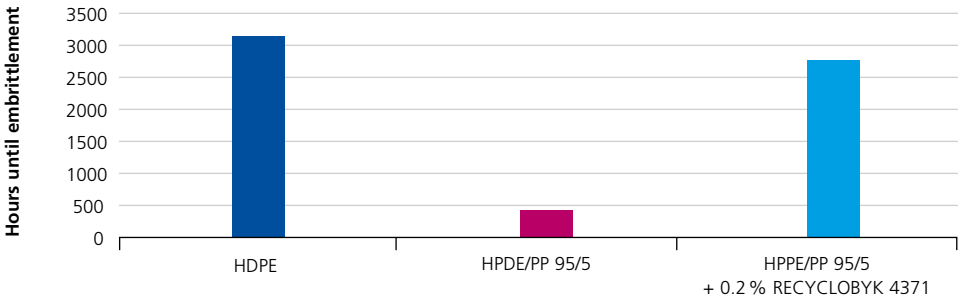
- Polyolefin blends with different compositions, e.g. bottle fractions or multi-layer films
- Polypropylene contaminated with other polymers
- Polypropylene exposed to aggressive substances, as in battery-housing recyclates
- Mixed plastics from household and industrial waste
- Polyolefins exposed to long-term UV radiation for use in outdoor applications, e.g. grids, barrels, pallets, and garden furniture

# Restabilization of recycled thermoplastics – practical examples

### Embrittlement of HDPE/PP blends (e.g. bottle fractions)

A typical blend resulting from bottle recycling, for example, is a mixture of HDPE (bottle) and PP (lid). Pure HDPE exhibits good resistance to embrittlement during heat aging. The stability is significantly reduced by blending with PP, even at a low blend ratio (HDPE/PP 95/5). By using RECYCLOBYK, the time to embrittlement of the blend can be increased almost six times (G. 04).

## Embrittlement of HDPE/PP blends (aging at 120 °C)



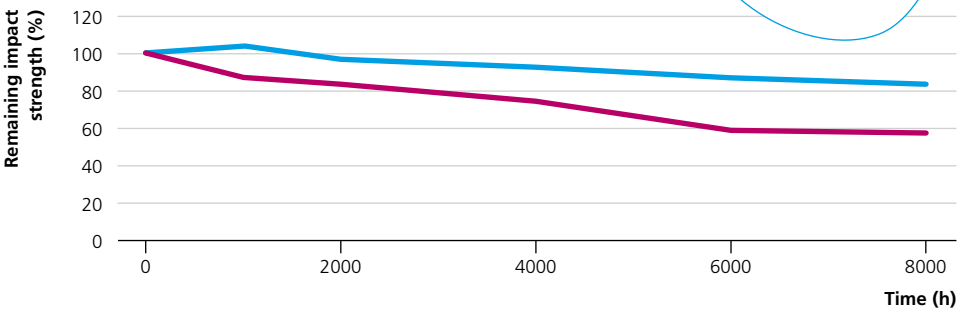

G. 04

### Aging of recycled HDPE (e.g. garden furniture)

Recycled HDPE (rHDPE) becomes brittle as it ages. Since, for example, garden furniture is exposed to different weather conditions, the use of rHDPE outdoors is only possible to a limited extent. After approx. 3000 hours of artificial weathering, the impact strength is only 80 % of the initial value. RECYCLOBYK enables the rHDPE to be used in this area as well. Even after 8000 hours, the impact strength is still over 80 % of the initial value (G. 05).

## Remaining relative impact strength of rHDPE during artificial weathering

**Artificial weathering:**
- Xenon lamp
- 60 % relative humidity
- Water spray




rHDPE
rHDPE + 0.2 % RECYCLOBYK 4372

G. 05

# Recyclates from the automotive industry

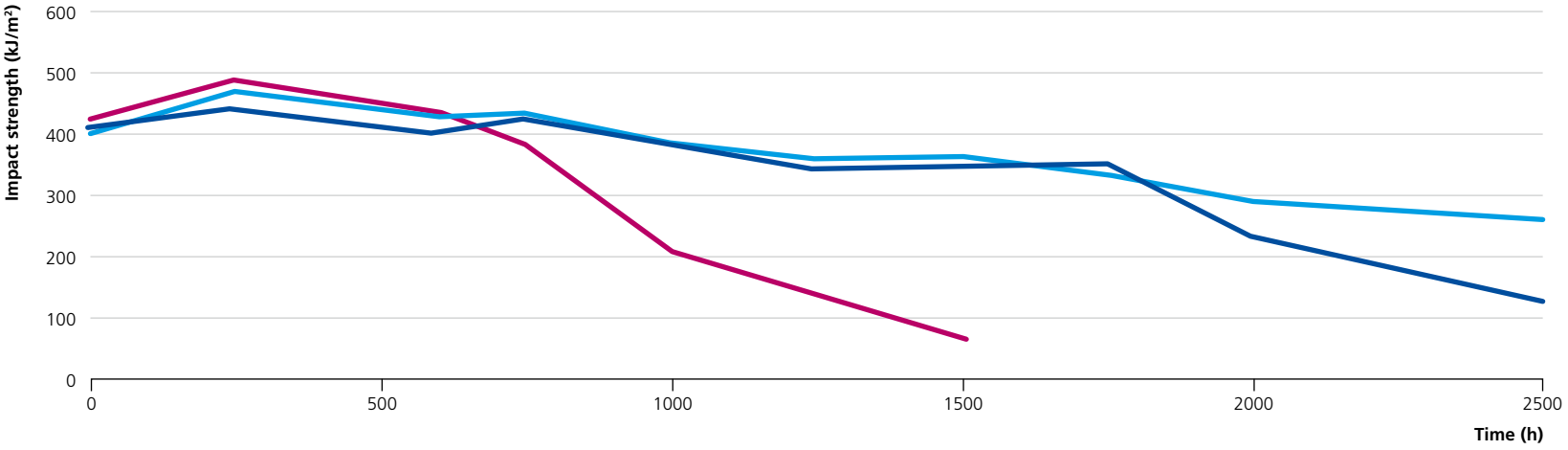
In the automotive industry in particular, plastic components have now replaced many original materials. Components made of plastics are lighter and can be shaped to meet design requirements. In Europe, however, the automotive industry is obliged to manufacture an increasing proportion of these plastics from recycled materials.

Bumpers are a typical example for this. The PP used is modified with EPDM in regard of impact strength, and fillers are added to achieve the desired price and strength level.

The recyclate may contain solid impurities such as paint residues. BYK products neutralize the negative effect of these impurities and thus increase the impact strength.

Even 0.2 % paint residues in the recyclate cause a significant drop in impact strength during aging. After about 1500 hours, an impact strength around 15 % of the original value can be measured. RECYCLOBYK products lead to a compatibilization of the paint impurities and a restabilization, so that after 1500 hours, 90 % of the original impact strength is still present (G. 06).

## Impact strength of recyclate contaminated with paint residues (aging at 135 °C)




Contaminated recyclate + 0.7 % RECYCLOBYK 4373 + 1.2 % RECYCLOBYK 4373

G.06

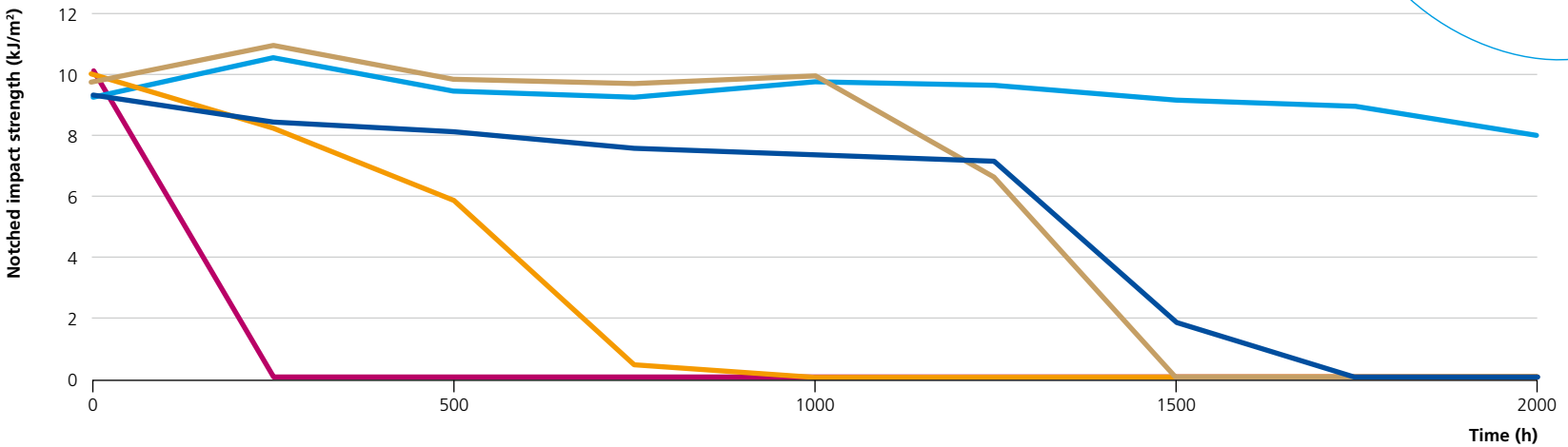
Another special application example is the recycling of used battery housings. Through a take-back system, batteries from automobiles are collected by manufacturers or contract companies with a very high return rate and recycled there. Even in electric vehicles, 12 V batteries continue to be used in addition to the high-voltage battery for the drive, as the main battery is disconnected from the vehicle network when switched off.

The polymers used for the housings (in this case PP) are exposed to aggressive substances during their time of use, meaning the recycles obtained may still contain acid and metal residues despite cleaning. Direct reuse would significantly accelerate the aging of the plastic. For this reason, the use of special additives, such as RECYCLOBYK products, is necessary for restabilization.

For testing, specimens are subjected to accelerated artificial heat aging conditions at 135 °C or 155 °C and the time to embrittlement is measured. Without additives, the accelerated heat aging lifetime in the example shown is less than 250 hours for the unstabilized compound. By using 0.2–1.0 % RECYCLOBYK, this time can be extended to more than 2000 hours, significantly exceeding a standard stabilizer package (1250 hours) (G. 07).

## Impact strength of recycle contaminated with acid and metal residues (aging at 135 °C)

The results show that the use of a standard stabilizer package improves aging properties, but even at 1 %, it only performs about the same as 0.2 % RECYCLOBYK.




G.07

The improved performance is evident in terms of elongation, tensile strength, and modulus, as well as Charpy impact strength.

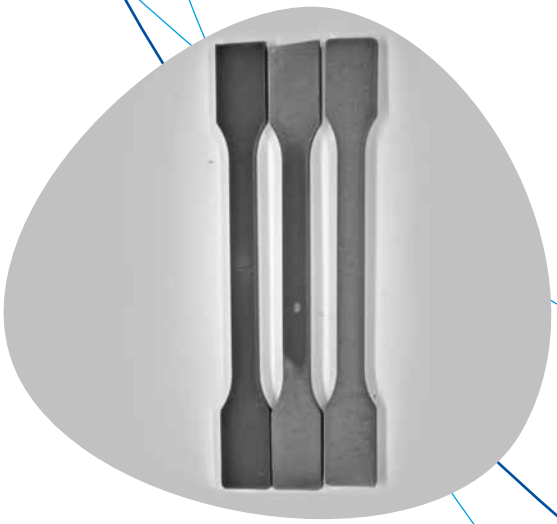
### Additives compared to the non-stabilized zero sample (= 100 %) before aging

| Hours at 135 °C | Control | Standard stabilizer package | | | RECYCLOBYK 4371 | | |
|---|---|---|---|---|---|---|---|
| | | 0.2 % | 0.5 % | 1.0 % | 0.2 % | 0.5 % | 1.0 % |
| 250 | 0 | 101 | 108 | 111 | 105 | 110 | 114 |
| 500 | 0 | 89 | 100 | 108 | 99 | 109 | 108 |
| 1000 | 0 | 0 | 96 | 107 | 92 | 109 | 110 |
| 1250 | 0 | 0 | 46 | 89 | 89 | 105 | 107 |
| 1500 | 0 | 0 | 0 | 0 | 5 | 105 | 105 |
| 2000 | 0 | 0 | 0 | 0 | 0 | 99 | 102 |

Standard stabilizer package: B-2

T.01

The results show the combined relative performance in terms of elongation, tensile strength, and tensile modulus, as well as Charpy impact strength compared to the non-stabilized control sample (= 100 %). The use of a standard stabilizer package improves the aging properties, but even at 1 %, it only achieves around the same performance as 0.2 % RECYCLOBYK.



# Recyclates from the packaging industry

A polymer rarely directly fulfills the complete required property profile. Since the strengths and weaknesses of the different polymers are very different, the properties are often combined. The combination can be in the form of a blend (e.g. PC/ABS or HIPS), or by joining the unmixed polymers, as in the case of a multi-layer film or a hard-soft composite. Although these polymer combinations are extremely beneficial in their initial use, they lead to significant challenges when recycled.

## LLDPE and polyamide in multi-layer films

A particularly challenging area of application is the recycling of multi-layer films. These typically combine the unique properties of different polymers to achieve the required performance. The main focus is on extending the shelf life of food products by providing a good barrier against oxygen and moisture. One polymer combination commonly used for this purpose is polyamide and LLDPE. The good barrier properties and the high strength of a polyamide complement the advantages of LLDPE, such as high impact and puncture resistance.

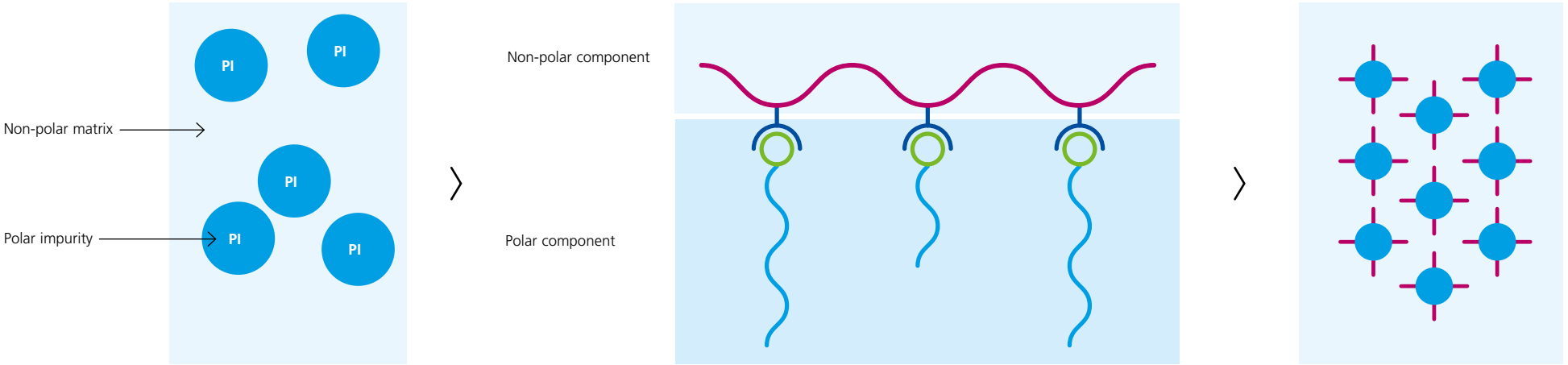
The separation of the two polymer layers is currently not possible during reprocessing on an industrial scale, since the less dominant phase (PA in this case) forms large polymer spheres in the LLDPE matrix during regranulation due to the different surface energies. This deteriorates the optical properties (especially transparency) of the material. The insufficient compatibility of the two polymers also leads to low mechanical resistances, especially in terms of elongation and impact strength. Compatibilization by using a highly functionalized SCONA modifier makes it possible to make the non-polar LLDPE compatible with the polar PA.

# Compatibilization with SCONA

## In situ formation of the amphiphilic compatibilizer


**Poor dispersion:**
Low interfacial adhesion = poor mechanical properties

**Good dispersion:**
High impact strength



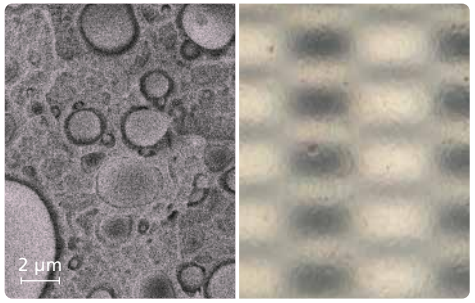

● Acid/anhydride group ● Amine group ● SCONA modifier ● Polyamide

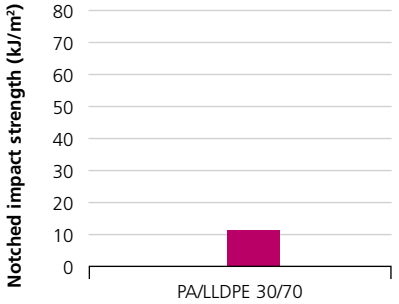
G.08

* Simplified reaction scheme with the amine end group, however the internal amide groups may also take part in the reaction.

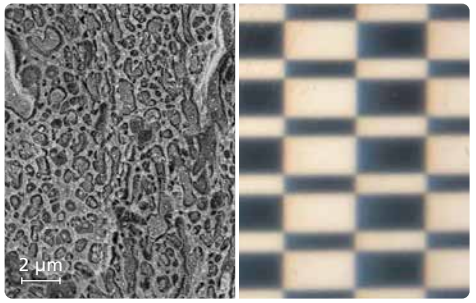
# Mechanical and optical properties of PA/LLDPE blends

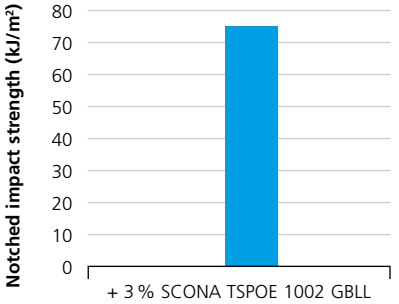
**PA/LLDPE 30/70**
Inhomogeneous material with poor compatibility, poor optical properties, and low mechanical resistance.




**With SCONA modifier**
With a highly functionalized SCONA modifier for excellent compatibility and improved mechanical and optical properties.




G.09

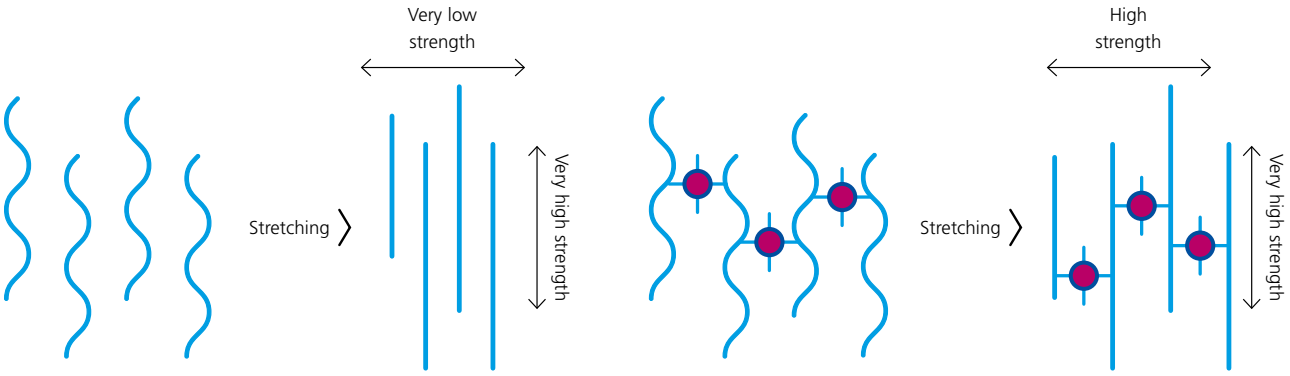
The use of the modifier leads to better bonding of the polyamide to the polyolefin phase and thus to finer distribution. This improves the mechanical and optical properties. The best possible distribution is achieved by using a twin-screw extruder.

### PET strapping

Recycled PET can be available in different quality grades. High-quality rPET can be used to produce beverage bottles from 100 % rPET, whereas lower grades are used for strapping.

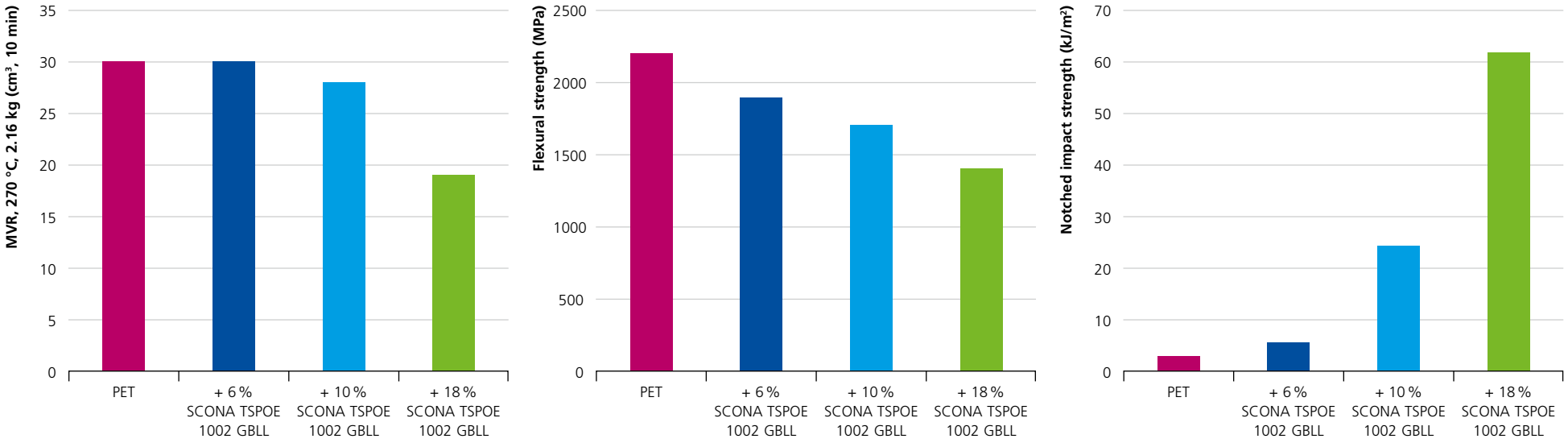
PET strapping is stretched up to five times in the direction of flow during manufacture. This results in the required tensile strength, but causes poor tear resistance along the PET molecules aligned in parallel by the stretching. The strapping is susceptible to splicing. SCONA modifiers can create the necessary chemical bonds between the single PET molecule chains to prevent further tearing.

## Improving strength in PET strapping




G. 10

## The use of SCONA modifiers has an influence on MVR (melt volume rate), flexural strength, and notched impact strength.




G. 11

# Fiber-reinforced plastics with recyclates

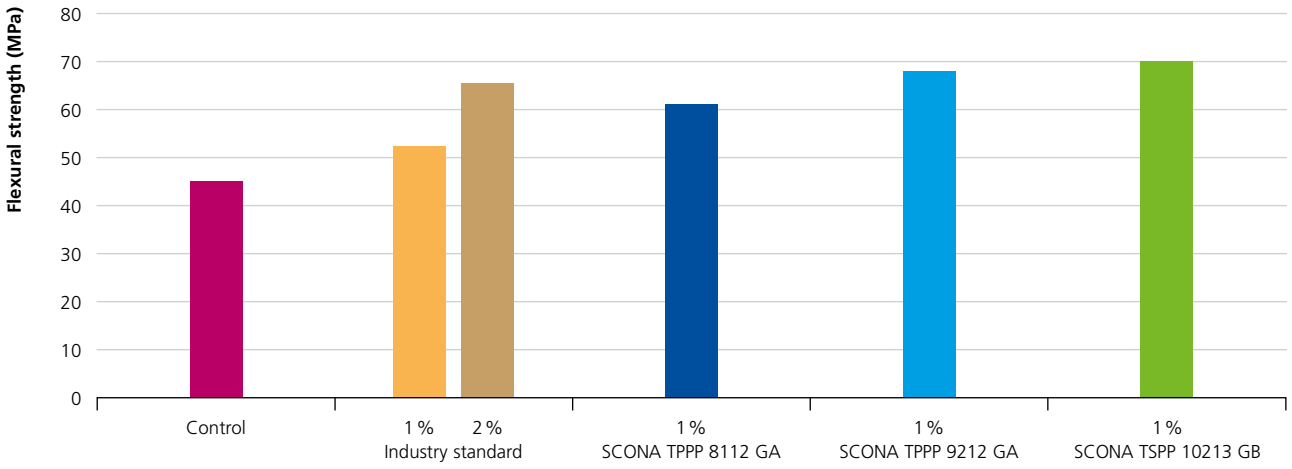
Various fibers can be used to improve the properties of recycled materials. This can be done for price reasons, but also for environmental protection aspects or to enhance properties. Basically, there are two different types of recyclates:

On the one hand, fibers can be used in thermoplastic recyclates, such as in wood fiber-reinforced plastics (WPC) based on recycled polyolefin blends. On the other hand, recycled carbon fibers from secondary sources (rCF) can also be used in PP (PP-rCF), which is gaining popularity especially in the automotive industry.

Normally, recyclates are not of uniform quality, and mixtures of PE and PP are frequently found. The incompatibility of PE and PP, combined with polymer degradation, degraded processing aids, and consumed light and heat stabilizers make it challenging to achieve good results with conventional coupling agents to improve mechanical properties in WPC applications.

By using BYK products, good properties of wood fiber-reinforced recyclates can be achieved even at low input quantities, e.g. due to a very high degree of grafting (G. 12).

## Mechanical properties of recyclates (PE/PP) reinforced with wood fibers (50 %)




G. 12

Waste and components from the automotive sector containing carbon fibers can be recycled, and the recycled carbon fibers obtained from this can be used in thermoplastics with only a slight cost difference compared to glass fibers. Unlike glass fibers, however, such recycled carbon fibers do not have a sizing that allows better compatibility with polyolefins such as polypropylene. Nevertheless, in order to achieve good adhesion between the matrix and fiber, a coupling agent with a high degree of functionalization is required. BYK products are ideally suited for this purpose.

## Relative property profile of 4 % SCONA TSPP 10213 GB in PP with 30 % carbon fiber compared to the industry standard and to a control sample without a coupling agent


G. 13

# Reduction of VOC and odors

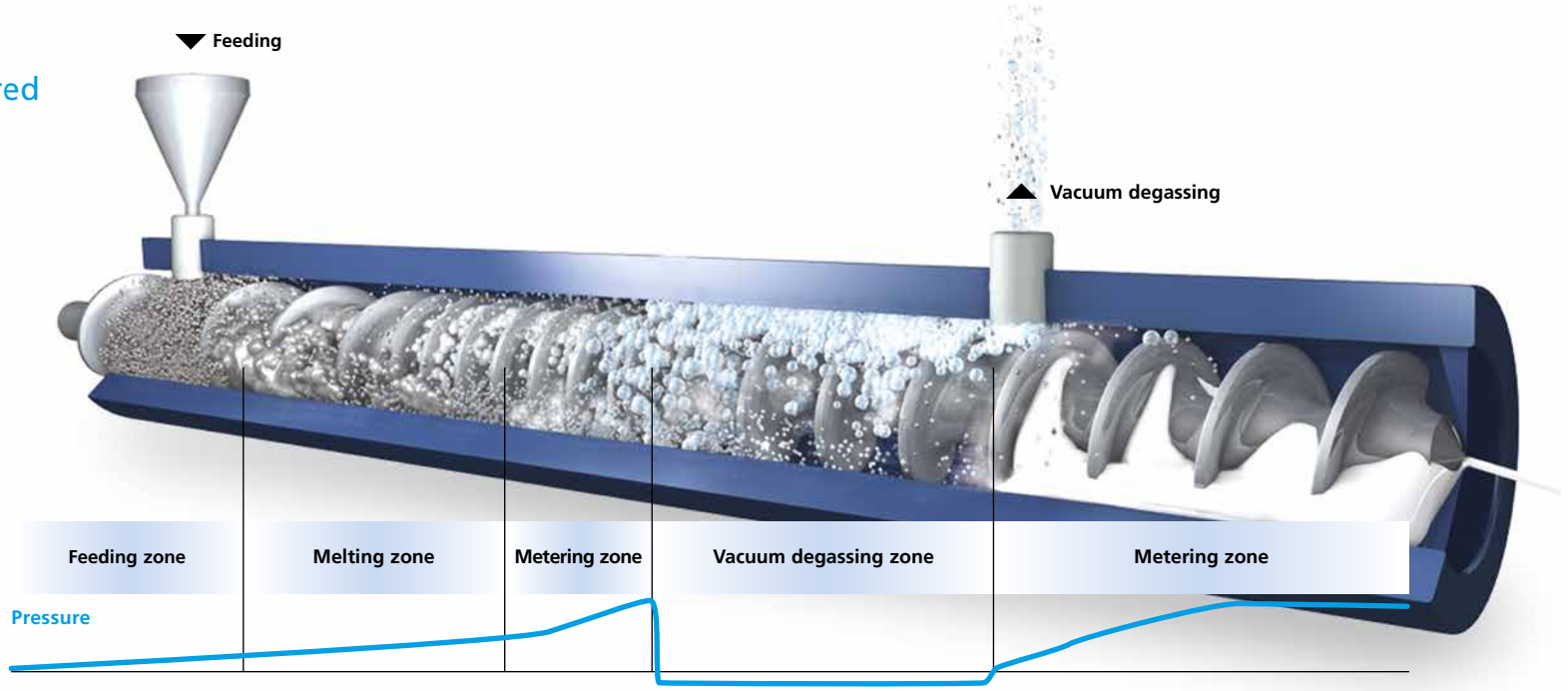
When thermoplastics are recycled, the type of pre-processing can have a significant impact on the quality of the final product. In addition to affecting physical properties and resistances, processing can increase odors and volatile organic compounds in the recycled plastics. Washing of the recyclate is very limited, as this only reaches the surface, but VOCs (volatile organic compounds) are present throughout the plastic and migrate back to the surface and ambient air. A popular option is the use of vacuum degassing during processing. Mixing the material maximizes the surface area, and the high temperature and vacuum increase the mobility of the VOCs, partially eliminating them. Other aids include the use of activated carbon, zeolites, or entraining agents such as water, $CO_2$, or nitrogen.

This is where BYK's products come in. The two-stage mode of action can be clearly illustrated using the specific example of BYK-MAX P 4200:

**Step 1**
During extrusion, the active ingredient is released. In interaction with the temperatures in the extruder and the shear forces, microfoam is formed in the melt, which absorbs odor and VOC components.

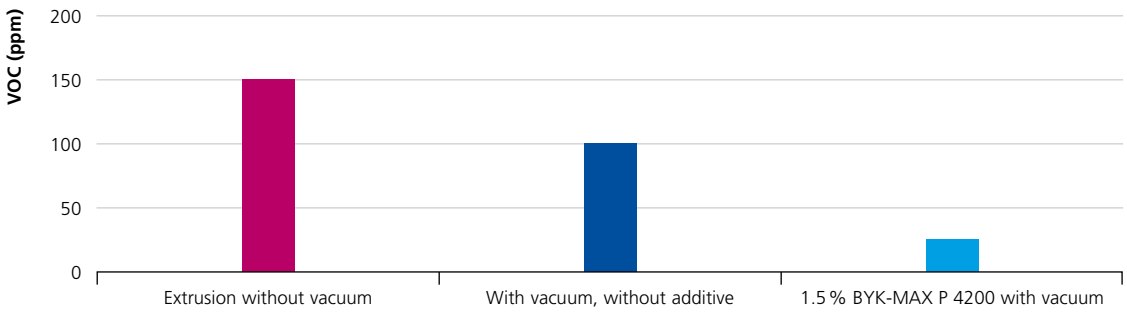
**Step 2**
During the subsequent vacuum degassing, the microfoam is removed from the melt together with the impurities contained.

## Strong degassing is required




**Pressure build-up during extrusion**

## VOC reduction in finished parts made of PP-GF (30 %) with BYK-MAX P 4200, measured according to VDA 277




G. 15

### Odor reduction with BYK-MAX P 4200 according to VDA 270 in finished parts made of PP-GF (30 %)

| | VDA 270 |
|---|---|
| Extrusion without vacuum | 4–5 |
| Vacuum with 50 mbar | 4–5 |
| 1.5 % BYK-MAX P 4200 and 50 mbar vacuum | 2–3 |

T. 02

## Odor

How is the odor actually determined? By smelling. Even though there are already approaches to analytically determine odor with measuring instruments, the human perception of odor is still the preferred and simplest method. A defined amount of the sample is conditioned in a glass container and then evaluated according to the German school grading system:

1 means no odor is perceived at all, 6 smells unbearable. 2–3 means perceptible odor, but not disturbing. For the results shown here, the sample was exposed to 80 °C for 2 hours.

TP-A 8 05/2022

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