Strategies for Recycling Plastic Products with High Added Value

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Plastics remain the most sustainable option for many of the sectors that use them, including the packaging, automotive, healthcare, construction and textile industries, given that their carbon footprint is often smaller than that of alternative materials such as glass, metals and ceramics due to plastics' low weight and the ease with which they can be processed. If these materials are properly disposed of and separated at the end of their useful life, they also have high recycling and recovery potential; this, in turn, further reduces their carbon footprint and their cost, thereby making them even more attractive for multiple applications. However, sometimes it is necessary to re-adjust their properties.

The major challenge when it comes to dealing with plastic product waste, lies in ensuring that they are sorted into the correct streams for recycling or recovery, thus preventing plastics from ending up in landfill, or even worse, in the natural environment. Once the different plastic materials have been separated, there are several treatment and recovery strategies. These depend primarily on their composition, origin and intended application, since a specific methodology must be followed in each case to ensure that the end product meets the requirements of the target sector. The main strategies include mechanical recycling (to obtain plastics), chemical recycling (to obtain substances) and energy recovery (to obtain energy). The most common strategies at global level are mechanical recycling and incineration with energy recovery, although chemical recycling is increasingly gaining momentum.

Recycling vs Incineration

Mechanical recycling has traditionally been reserved for very specific plastic streams, such as single-material products, and for relatively clean plastics, while incineration (with or without energy recovery) has been used for all other materials, including products with a complex composition (multilayered and overmoulded products, for example), unregulated and mixed source streams, and very dirty materials. This trend is changing due to improvements in separation and decontamination technologies and waste management systems, and the optimization of chemical recycling technologies and their capacity. The main drawback of mechanical recycling processes is that the materials obtained are commonly considered to be of poorer quality and are intended for products with lower added value or specifications, a trend that is also changing thanks to upcycling, also known as creative reuse, where the material obtained has a similar or even improved performance with respect to the original product. The term upcycling is also currently used to refer to chemical recycling in which monomers, fibres and other high-quality and high-purity substances are obtained from plastic waste that is difficult to recycle through mechanical means. The resulting materials can once again be used as raw materials in the manufacture of plastic products with high added value.

Recyclability: the concept

Whether a material is considered recyclable depends on various factors. In the case of plastic materials, the main requirement is that they be thermoplastic; in other words, they can be remelted and processed using conventional equipment. Accordingly, the vast majority of plastic materials are recyclable. However, to ensure that this is viable at industrial level, it is important that the waste stream for each material be sufficiently high and easily separable from the others. This has not been possible in the past, at least when it comes to post-consumer waste, due to the high diversity of materials and compositions. The main streams of this kind of waste generated in sufficient quantities for recycling are polyolefins (LDPE, HDPE and PP) and PET, most of which come from the packaging sector and are disposed in public-space recycling containers. Moreover, there is a growing stream of post-consumer waste from other sources, such as technical and/or reinforced materials used in the electrics/electronics, construction and automotive industries that consist mainly of matrices such as PP, PVC, PC, ABS, HIPS and PBT. These new streams can be used to recover high-performance materials and reduce the amount that ends up in landfill sites.

Fig. 1. Mixed stream consisting of materials recovered from marine litter.

Improved Properties: Upcycling

Once the plastic materials, from either post-consumer or post-industrial sources, have been collected for use as raw materials in the manufacture of other products, additional criteria must be taken into account. These relate mainly to the regulations and legislation that apply to these new products.

After each processing phase and use, plastic materials undergo different decomposition and oxidation processes (due to their exposure to the sun, heat, humidity, etc.), which diminish their mechanical properties and appearance. The mechanical recycling process is no exception. Products made from recycled materials therefore tend to have lower specifications. However, this can be prevented through the use of additive systems, which greatly improve the performance of these materials. The appropriate substance used to prevent or minimize this process depends on the decomposition mechanism of the plastics (oxidation, hydrolysis, etc.).

The upcycling process during mechanical recycling aims to restore mechanical and rheological properties, reduce odours and improve visual aspects. To achieve this, additive systems are incorporated, such as mineral fillers and fibres, impact modifiers, compatibilizing agents (especially in the case of mixtures or composite materials), whitening agents, flame retardants, fragrances and chain extenders.

Fig. 2. Process to improve properties through the use of special additive systems.

The process to upcycle waste streams always takes account of compliance with the regulations applicable to the product, mainly with respect to its mechanical performance, as well as compliance with sector-specific legislation. For example, in products containing a recycled plastic material to be used for the manufacture of a food contact container, the appropriate streams must first be properly separated and undergo different washing and decontamination processes, after which is analysed to certify their safety. In the event that the materials are intended to be used for a higher value-added application, such as in the automotive industry, the appropriate stream and treatment must be selected, but it may also be necessary to modify the material by adding certain additives to ensure that the finished product meets the required specifications. It is also important to ensure that the end product does not contain legacy substances from the recycled material, such as halogens and heavy metals, which were commonly used in certain additive systems some years ago, but whose use is now restricted by more recent legislation because of the high risk they pose.

Decontamination and Odour Reduction

During reprocessing and improvement of the mechanical and rheological properties, a decontamination and odour removal process may also be applied to improve the sensory features of the end product, especially when it comes to post-consumer materials.

In the case of decontamination, this can be done in two ways: removal of volatile substances and removal of infusible contaminants. The devolatilization process uses washing agents such as water, carbon dioxide and specialized surfactants to extract the volatile substances from the molten plastic that cause odours in recycled plastics, while the process to remove solid and infused substances employs systems for filtering the molten material. Both processes are performed on a continuous basis in both single-screw and double-screw extruders.

Upcycling at AIMPLAS

Upcycling a low-performance recycled plastic material starts with the prediction and assessment of the properties that will be affected once the recycled material has been processed, thereby impacting its performance (impact resistance, colour, odour, fluidity, etc.). This analysis is based primarily on knowledge of plastic materials and their degradation mechanisms, and on a qualitative and quantitative assessment of control samples. If this initial analysis is not carried out, the upcycling process may not be effective and may incur unnecessary costs in terms of additives, time and energy.

Depending on the properties identified as those that will be most affected by upcycling and as critical to obtaining a high-quality product, the appropriate additive system is selected to counteract the degradation effects caused by the material's poor specifications. To determine the optimal combination and content of each additive, it is advisable to carry out a small-scale study in an laboratory internal mixer, for example. This makes it possible to observe the effect on the torque and, therefore, the effect on the viscosity of the additives used. The optimal formulation can subsequently be scaled up to a continuous mixing system to obtain the improved recycled product, before being checked to ensure that it meets all the requirements for the application. If these requirements are not fully met, an optimization phase can be performed to fine-tune the additive systems and mixing conditions.

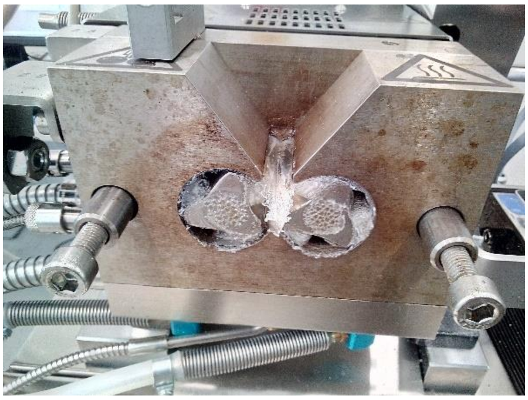

Fig. 3. Additivation study in an in-company mixer.

AIMPLAS has conducted many projects related to the upcycling of recycled materials from multiple waste sources. For example, the goal of projects such as OCEANETS (EASME) and REPESCAPLAS (Biodiversity Foundation) is to reuse materials from marine litter, composed primarily of PET, PA, PP and PS, which have undergone a high degree of degradation through exposure to the elements. To achieve this, the main objective when processing these materials is to improve their rheological properties, thereby restoring their molecular weight and, in turn, improving their mechanical properties. These improvements mean that highly degraded materials can be used in products with high added value, such as high-end textiles.

Other projects, such as REMADYL (H2020) and NONTOX (H2020), seek to remove legacy substances that are currently classified as harmful, such as lead-based stabilizers and phthalates in PVC, and halogenated flame retardants in engineering plastics. The abovementioned filtering and devolatilization techniques are used to remove these substances and thus obtain “rejuvenated” products that comply with current legislation and can therefore be used in a wide range of applications.

In addition to participating in a vast range of research activities related to the production and use of recycled plastics, AIMPLAS is involved in processes to certify suppliers and manufacturers of plastic materials through its position as an accredited EuCertPlast auditor and an authorized laboratory for Blue Angel and Recyclass accreditations.

AIMPLAS conducts research to meet its commitment to environmental sustainability. As a result, companies in the sector will be able to integrate circular economy criteria into their business models and turn the legislative changes that affect them into opportunities to improve efficiency and profitability and reduce environmental impact. In this regard, AIMPLAS also carries out research in areas such as biodegradable materials and products, the use of biomass and CO_2.