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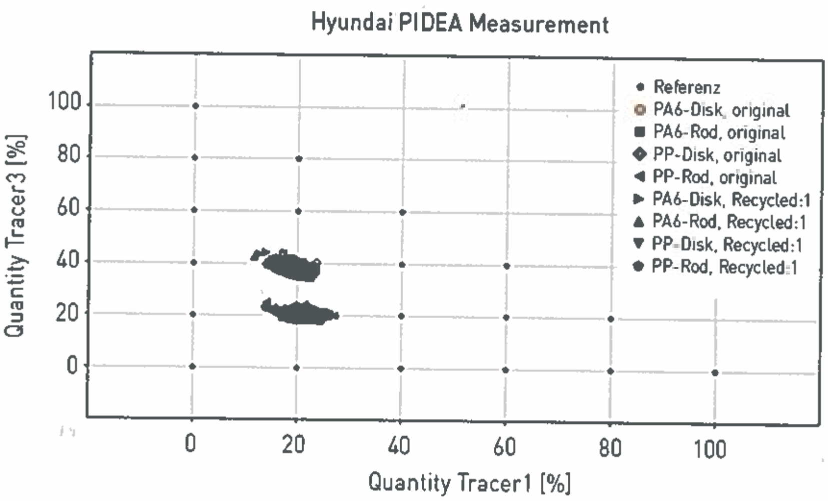
Increasing quality and efficiency of plastic sorting

Reducing waste and preserving resources by setting up a "real closed loop" for plastics is one of today's major challenges. Regulatory efforts, as in Europe, for example, have been directed towards increasing the recycling rates and content of recycled plastics in new products. Achieving these ambitious goals will only be possible if the plastic recyclates are of comparable quality to virgin materials. There is a consensus in research that this is only feasible if the mechanical recycling processes are fed with highly pure and well-defined material fractions. Hyundai Motor Group, Polysecure and SKZ have conducted a feasibility study on a new type of sorting technology. The results indicate that reliable solutions already exist for sorting plastic to produce high-quality recyclates.



Color coded plot for each measurement of marked PA6/PP Disk/Rod

Source: Polysecure

One of the greatest challenges of our time is to reduce the size of the world's carbon footprint to counteract global warming, which involves both reducing the amount of waste generated and preserving resources. Since 1950, the production of plastics worldwide has surged from two million tonnes to over 400 million tonnes and is expected to double or even triple by 2050. This growth has led to a "take-make-waste" pattern, causing significant resource waste and environmental pollution. Around 60% of all plastics produced remain in the environment, and current methods of plastics production and disposal account for approximately 4.5% of global greenhouse gas emissions. To combat this trend, implementing a circular economy in which resources are reused is crucial in order to protect the climate and promote sustainability.

Legislation plays a key role in driving forward the corresponding developments. For instance, the European Commission's proposal for a regulation on circularity requirements for vehicle design and end-of-life vehicle management mandates that 25% of the plastic used in new vehicles must come from recycled sources, with 25% of that recycled plastic originating from end-of-life vehicles.

Achieving this goal requires a combination of measures, including circular product design, standardising plastic types, organising extensive take-back and separate collection systems, and improving the flow of information between all those involved. A crucial aspect is to enhance the sorting of the various plastic materials. By substantially increasing sorting yield and accurately sorting the types into well-defined material fractions, much more plastic can be recycled in a carbon-efficient manner. This principle is driving the development of the innovative Sort4Circle® technology, which aims to initiate a new era of high-quality sorting and recycling.

Compared to current plastic waste sorting methods, Sort4Circle® introduces a novel approach to both materials handling and detection. In the new single-step sorting process, all objects are separated, fully identified and sorted in one single flow. Additionally, the tracer-based sorting (TBS) method, developed and patented by Polysecure, can be employed. This method uses very small amounts of fluorescent additives (tracers) either on or in objects, which fluoresce with specific emission lines when suitably activated. These tracers can be mixed in predefined ratios, producing fluorescence codes that can be used as highly efficient and reliable sorting codes (e.g. Code 10 contains tracer 1: 20%, tracer 2: 60%, tracer 3: 20%). This sorting code system allows plastic waste to be more accurately sorted into defined categories (e.g. PA6, PA6.6 or PA12).

The objective of this feasibility study was to demonstrate the performance of efficient fluorescent sorting tracers. The results were verified through various tests and measurements. The study determined the statistical key figures for tracer detection and evaluated the influence of the markers on the technical properties of components made from virgin material and 100% recyclates derived from components with tracers.

The materials used in this study, PP and PA6, were supplied by Hyundai Motor Group and moulded into discs and tensile bars. The tracers were added during the injection moulding process using marker masterbatches.

Additionally, the study assessed the reliability of the Sort4Circle® single-step sorting mechanism employing tracer-based sorting.

The accuracy of tracer detection was tested using Polysecure's PIDEA system, a device developed by Polysecure, designed for objects to move in a circular path, ensuring dynamic motion and random orientation of the objects during the detection. As the object passes through the detection system at 3 m/s, the tracer fluorescence signal is measured at each round. The system then calculates the tracer ratio and code, which is represented as a data point in the corresponding plot.

In the feasibility study, Code 14 (tracer ratio: 20/40/40) was assigned to PA6, while Code 10 (tracer ratio: 20/60/20) was assigned to PP. For both materials, the tracer concentration was set at 10 ppm. The test specimen (8 discs and 8 tensile bars per material) were measured until 500 data points per material were collected. The results show no overlap between the data sets of the two codes, confirming that fluorescent tracers and tracer codes, different to any other sorting feature (e.g. watermarks, AI, NIR), provide reliable detection and differentiation and there is an absolute absence of false positives. Especially the latter finding ensures very high purity of the fractions (>99%) thus sorted, which is key for high-quality recycling, particularly of food-contact plastics and many other applications in a future circular economy of plastics.

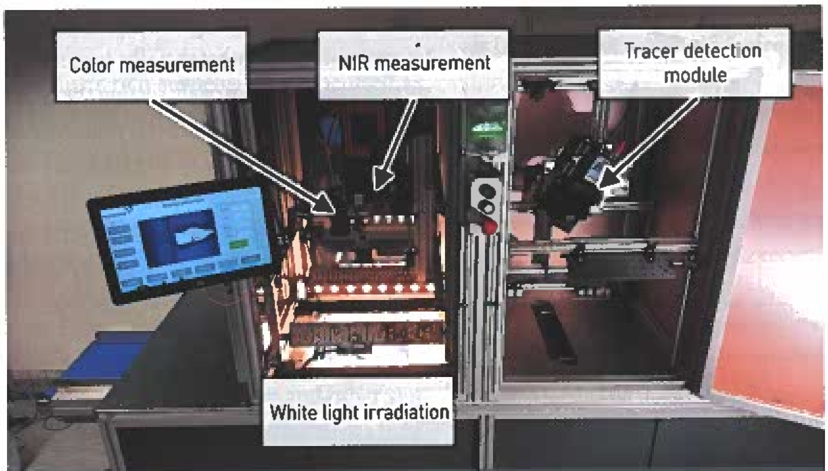
To evaluate the potential influence of tracers on the mechanical properties of plastics, various material tests, conducted in compliance with ISO standards, were performed at the German Plastics Centre (SKZ).

The tests were performed on specimens made of virgin PP and PA6 with a tracer concentration of 10 ppm. Specimens without tracers served as the reference. To analyse the effect of tracers in recycled materials, the same tests were performed on specimens made from sorted and reground PP and PA6 containing the tracer.

The results for PP specimens generally indicate no relevant differences between plastic samples with and without markers. Furthermore, the samples that were subjected to one-time thermal stress by injection moulding showed comparable values, even after conditioning. The only discrepancy was the loss of tensile strength in the reground, recycled sample after 1,000 hours of conditioning at 140°C. Since the recycled and reground PP specimen underwent a second injection moulding process, the degradation is likely due to this second thermal stress, suggesting the material exceeded its tipping point.

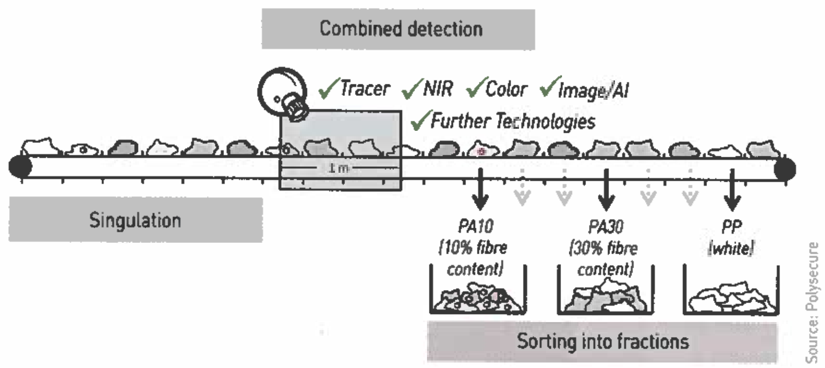
Conditioning PA6 at 140°C for 1,000 hours led to the complete degradation of the material, whether virgin, marked, or reground. This finding was evident from the tensile test results. Virgin material specimens, stored the longest, absorbed the most moisture, influencing the tension and flexural strength results. This hydrolytic effect was apparent after one day at 23°C and 50% humidity but was mitigated after conditioning for 500 hours at 90°C, making the results comparable for all specimens. However, under 95% humidity and 90°C for 500 hours, the hydrolytic influence re-emerged across all specimens. The impact strength test showed a significant hydrolytic effect on parts conditioned for 500 hours at 95% humidity and below 90°C, highlighting the material's increased toughness due to water absorption.

Overall, the results of the material tests showed no discernible impact of the markers on the mechanical properties of the plastic.



The combined detector that classifies each piece of material according to color, polymer (NIR) and tracer code. Source: Polysecure

Basic principle of the Sort4Circle technology



However, the effects of aging during processing or use must be considered for recycled materials.

To fulfil the requirements of a "real closed loop", it is not sufficient to sort plastics according to individual polymer types (i.e. to distinguish PP from PE, PA, etc.). A distinction must also be made within a polymer type (i.e. PA6 from PA6.6, PA12, etc.) and according to different additives and fillers and, if applicable, filler contents. The aim is to reuse the recycled plastics to manufacture equivalent products ("closed loop"). However, this also means that a distinction needs to be made between the many different fractions during sorting. To address this challenge, the innovative Sort4Circle® sorting technology was developed.

The current state of automatic plastic waste sorting involves a multistep process tailored to the input stream (e.g. industrial or household waste) and target fractions. It begins with cutting, shredding, and classifying to produce suitable object sizes. Sorting utilises various methods: wind sifting separates light films from heavier items, magnetic and eddy current separators remove iron and nonferrous metals, and sensor-based optical methods distinguish between different types of plastics. Near-infrared (NIR) spectroscopy, the most common method for sorting lightweight packaging, identifies specific plastics such as polypropylene (PP) by detecting characteristic absorption bands. Once identified, the plastics are then blown out via compressed air valves and separated from the residual stream. Consequently, for each new polymer fraction to be sorted, an additional sorter is needed.

Compared to the status quo in plastic waste sorting, Sort4Circle® takes a new approach in terms of both materials handling and detection. In the new single-step sorting process, all objects are first separated, then fully identified once and sorted in one smooth process (comparable to letter sorting).

Pre-treatment and separation are carried out using several synchronised conveyor belts and/or other components that are suitable for transporting and aligning the sorted goods. This ensures that all parts are transferred to the sorter in a single row. The sorter itself is a tray sorter where each tray carries a single item. A new combined detector is positioned at the front end of the sorter, directly after the sorted items are transferred to the trays. Here, each individual object is characterised by a series of measurement techniques (combined detection) and classified with a decision logic according to the criteria defined for the respective sorting input. Based on this classification, each individual item is assigned to a specific collection container. The assignment is tracked by the control software, which ensures that the respective object is sorted into the respective collection bin without any error. In contrast, today's conventional pneumatic sorters create a significant level of error so that purely sorted fractions are not possible.

The key component and centrepiece of the Sort4Circle technology is the combined detector. It analyses each individual sorting object separately by measuring several of its physical properties: polymer material by NIR and MIR (black plastics) spectrometry, colour and image by VIS detection, and AI and sorting code identification by laser-based fluorescence measurement. The assignment to predefined fractions is then carried out based on the combination of all the collected measurement data. Additional measuring units for LIBS and other measurement methods can be integrated without major mechanical adaptations.

To evaluate the reliability of the Sort4Circle® single-step sorting mechanism, marked plastic samples were mixed with unmarked shredded polymers and fed into the system. Out of 1,212 objects identified as PP and 1,024 objects identified as PA6, only one object per fraction was incorrectly classified, resulting in 99.9% purity of the sorted fractions. Moreover, the sorting yield, i.e. the percentage of objects that were effectively identified and sorted, was well above 90%.

This feasibility study has demonstrated that tracer-based sorting technology provides plastics with an additional differentiation criterion for enhanced sorting. Tracer codes, based on predefined ratios, can be reliably identified without the occurrence of false positives. Using the singe-step Sort4Circle® system, results showed that both marked and unmarked objects can be sorted into the desired fractions with a high yield and level of purity. Furthermore, material tests conducted in the study showed that the markers had no discernible impact on the mechanical properties of the plastics and recyclates. The innovative Sort4Circle® technology provides a fundamentally new approach to sorting plastics into multiple fractions. Enhanced by tracer-based sorting, it enables precise differentiation, bringing us closer to achieving a truly "closed loop" recycling system.

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