HIGH PERFORMANCE PLASTICS *IN AUTOMOTIVE ACTUATOR APPLICATIONS*

Envalior

Imagine the Future

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Designing for reliability and performance while reducing weight, noise and cost of ICE, hybrid, and fully electric vehicles

Over the last two decades, the automotive industry has been putting great effort into reducing vehicle emissions by developing highly efficient modern internal combustion engines (ICE).

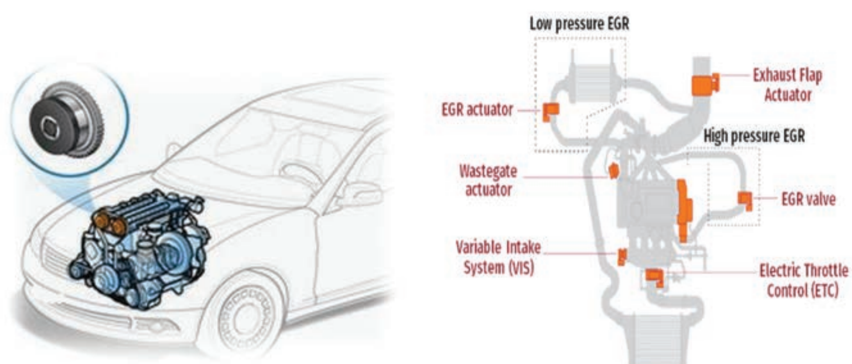
As part of this endeavor, various engine control units and actuators have been deployed to enable modern ICE vehicles to run at a high operating efficiency, helping to significantly reduce CO2 and particle emissions.

Examples of such engine management actuators include exhaust gas recirculation valves (EGR), various turbo actuators that are used in charged, downsized ICE vehicles (e.g., electric waste gate valves), electronic throttle control valves, (ETC), thermal management actuator valves and others.

As electrified and hybridized powertrains have proven to be an efficient way of coping with increasingly stringent emission requirements imposed by governmental bodies over the last decade, OEMs are adopting various forms of vehicle electrification. As result, different powertrain types with varying degrees of electrification have been introduced, resulting in various forms of hybrid vehicles and electric vehicles (EVs).

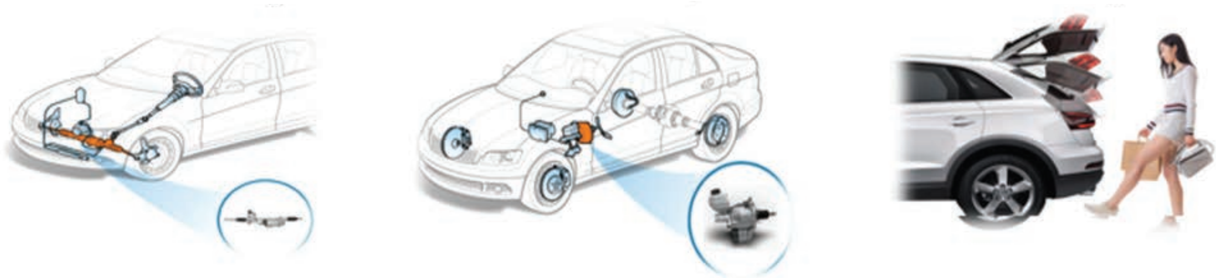
Today's hybrid vehicles are relying on downsized and highly efficient ICEs, as well as many proven ICE technologies. This includes a variety of engine management control units and actuators. At the same time, hybrid powertrains deploy electric drive motors, working in conjunction with ICEs, to propel vehicles forward at a more efficient operating point. Different variations of hybrid powertrain types have been developed over the past years, depending on their degree of electrification. These are often categorized as micro–hybrid, mild–hybrid, plug–in hybrid and fully–hybrid vehicles.

Compared to hybrid vehicles and their various existing forms, BEV powertrains rely solely on high–voltage batteries and electric motors to power vehicles forward. In addition to supplying energy to the main drive motors, the onboard high battery voltage enables additional functionalities, operating directly off the electric power rather than relying on various accessories traditionally



Modern ICE vehicles make use of a variety of actuators to control CO2 and particle emissions

ELECTRIC STEERING | ELECTRIC BRAKING | ELECTRIC COMFORT SYSTEM



Many vehicle functionalities are now becoming electric due to evolving electrification trends

used in conventional ICE powertrains. Examples of such accessories in a conventional ICE vehicle are hydraulic power steering, which is driven off the crankshaft, and the vacuum-based brake assist, which is powered by a dedicated vacuum pump.

EXCEEDING ELECTRIC POWER STEERING REQUIREMENTS

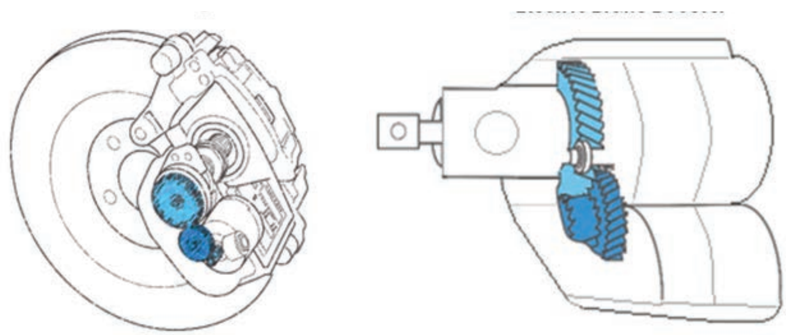
The electric version of power steering (EPS) has been used in all types of powertrains over the years, especially in EVs. This EPS system often comes with additional and more demanding requirements related to increased noise, vibration, and harshness (NVH) performance, as well as more stringent weight reduction requirements. The latter is highly relevant as it directly influences the EV's driving range, which is one of the key performance factors for EVs.

Depending on the EPS design, the actuation of the vehicle's steering rack is typically achieved with a motor and a gear reduction set (e.g., column-type and pinion-type steer assists). Such gear reduction sets increasingly employ high-performance plastic materials due to their lower stiffness and higher damping properties. Compared to metal gears, plastic materials help achieve a softer steering behavior with less vibration. Plus, the low weight and cost efficiency of plastics compared to metals are important considerations.

GAINING EFFICIENCY AND WEIGHT REDUCTION WITH ELECTRIC ACTUATOR BRAKING SYSTEMS

Like the steering system, electric actuators are being increasingly used on the vehicle's braking system. In addition to gaining improvements in efficiency and weight reduction, electric actuator braking systems are more compact and easier to install compared to traditional vacuum-based braking systems.

With conventional ICE vehicles, the brake assist is commonly achieved by means of a vacuum brake booster working together with a separately installed vacuum pump. With EVs, however, it is more common for these vehicles to be fitted with an electrically actuated brake assist that generates brake pressure without the need of an external vacuum pump, essentially making the vacuum pump redundant. The electric brake booster achieves the



ELECTRIC PARKING BREAK | ELECTRIC BREAK BOOSTER

Electric parking brakes and electric brake boosters as example applications of automotive electrification taking place in vehicle braking systems required brake pressure either by making use of electro-hydraulics, which rely on an e-motor and a pump, or via an electro-mechanical system, which is dependent on an e-motor and a set of gears.

The electric brake booster is mainly used in hybrid vehicles and particularly in EVs, which don't have a vacuum onboard like most ICE vehicles do. This presents an advantage for EVs as they don't have to provide the space or carry the extra weight associated with a separate vacuum pump, brake booster and hose connections. Other benefits include higher functional integration by combining braking functions into one single, compact, low weight unit.

Standard braking, regenerative braking and emergency braking are all known to be more easily achieved with a fully electric brake assist than with the traditional vacuum-assisted one. Also, the electric brake booster can generate brake pressure in a shorter amount of time than a traditional vacuum-based brake assist. This is an important feature, for example, in the event of emergency (autonomous) braking, adding to the vehicle's safety performance.

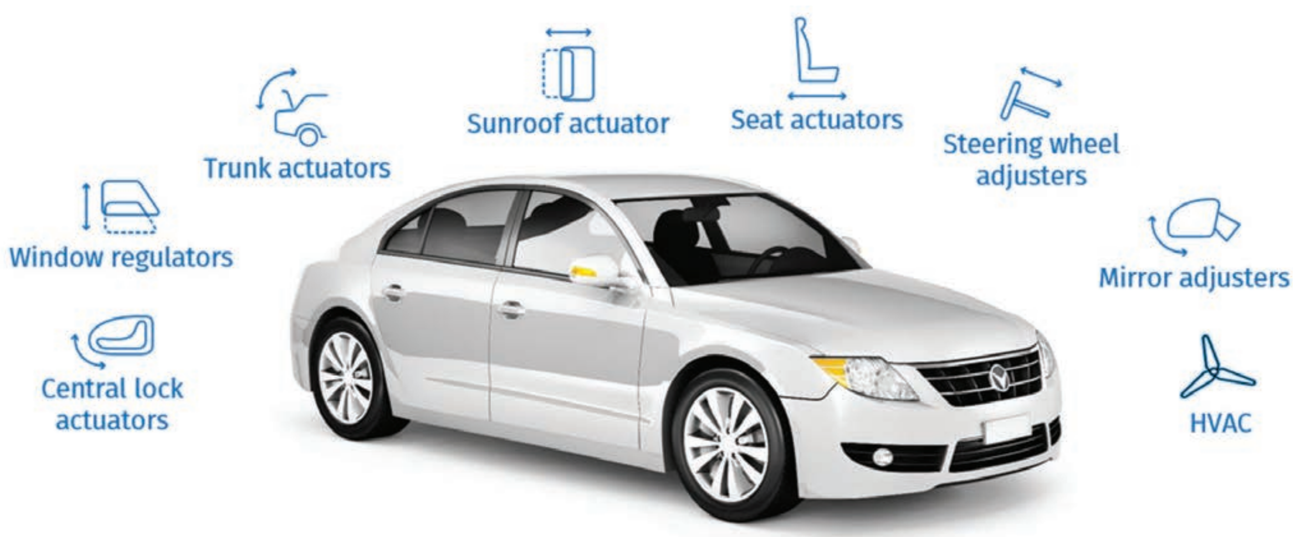
Another well-known example of electric brake actuators is the electric parking brake (EPB). Although the electro-mechanical parking brake has been used longer in vehicles with various powertrain types, the EPB has become increasingly common in the latest generation of vehicles, especially in hybrid cars and EVs.

Compared to traditional hand-lever-based parking brakes, the main benefits of the EPB include a simpler and more user-friendly operation. With a simple push of the button, the brakes engage and disengage. The EPB also consists of fewer components, which saves weight and requires less installation space, especially around the center console in the passenger cabin where space is traditionally occupied by the hand lever.

Like EPS systems, the electric brake actuators used in EVs are subject to more demanding weight and NVH requirements. Plastic materials are commonly used for the internal geartrain components of electric brake boosters to achieve lower weight and lower operating noise levels. Plastic materials offer a more cost-efficient solution compared to similar geartrains made of secondary operation intensive metals.

IMPROVING VEHICLE COMFORT SYSTEMS WITH ELECTRIC ACTUATORS

In addition to steering and braking systems, automotive electrification can also be seen in numerous other vehicle systems that aim to increase passenger comfort and the driving experience. Some examples include electrically operated windows, seats, and mirrors. Other examples of passenger comfort applications include electrically operated trunks/tailgates, which were initially seen on high-end SUVs and are now becoming standard features for many mid-range vehicles.



Various vehicle comfort systems are becoming electrically operated

All these vehicle functionalities rely on electric actuators to further help improve passenger comfort and the overall passenger driving experience. These actuators often rely on small e-motors paired with a set of gears. The gears provide the required output torque and speed to enable the functionality of the given application, be it the position adjustment of the mirrors and seats, opening and closing of the trunks/tailgates, etc. Some of the most common requirements of such actuators are durable and reliable performance, compact and low weight design, and low noise operation.

LIGHTWEIGHTING IS KEY TO ACHIEVING LONG DRIVING RANGE IN EVS

Compared to ICE vehicles, including hybrid vehicles, the advent of EVs has brought a significant benefit from the vehicle emissions perspective, enabling zero-emission driving.

According to the National Academies of Sciences, Engineering, and Medicine, the period from 2025-2035 could bring the most fundamental transformation in the 100-plus year history of the automobile as battery costs fall and EVs reach price parity with ICE vehicles, leading them to become the "dominant type of new vehicles sold by 2035."

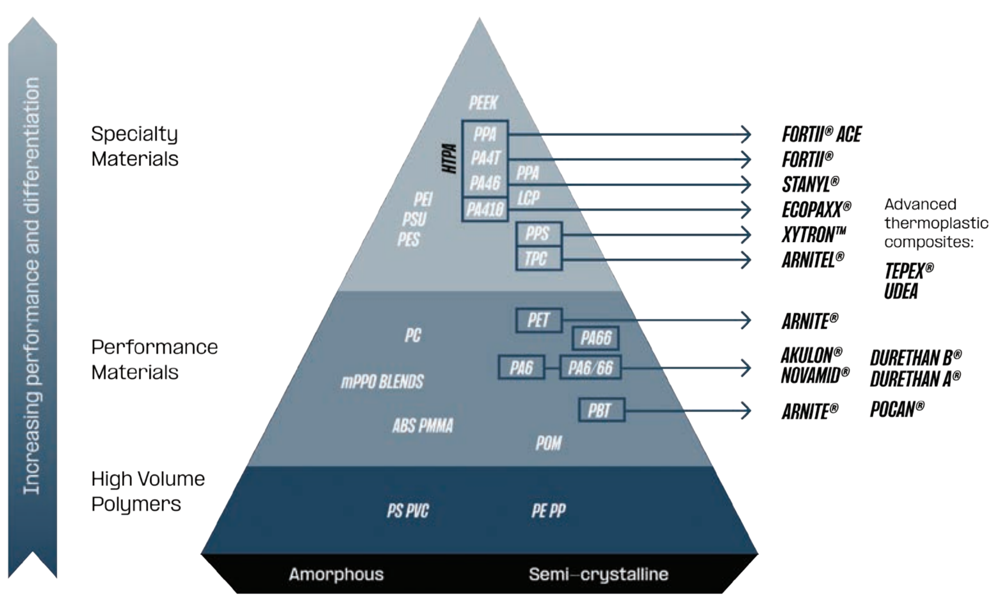
Yet, EVs have a relatively limited driving range compared to traditional ICE vehicles. The relatively high curb weight of EVs continues to be a design challenge for OEMs because it is directly linked to the vehicle's driving range. This is why vehicle designers are focused on taking the weight out of the vehicle as much as they can and where they can, both by adopting lightweight materials and by downsizing designs. In the materials department, lightweight metals and high-performance plastics are being used extensively, especially in cases where high cost-effectiveness is an important design consideration.

Engineering plastics have been used for many years in components for ICE vehicles and will continue to be even more relevant for vehicle weight reduction requirements. For EVs, weight reduction is one of the biggest factors for achieving a long driving range, therefore, it is one of the most important performance factors to consumers.

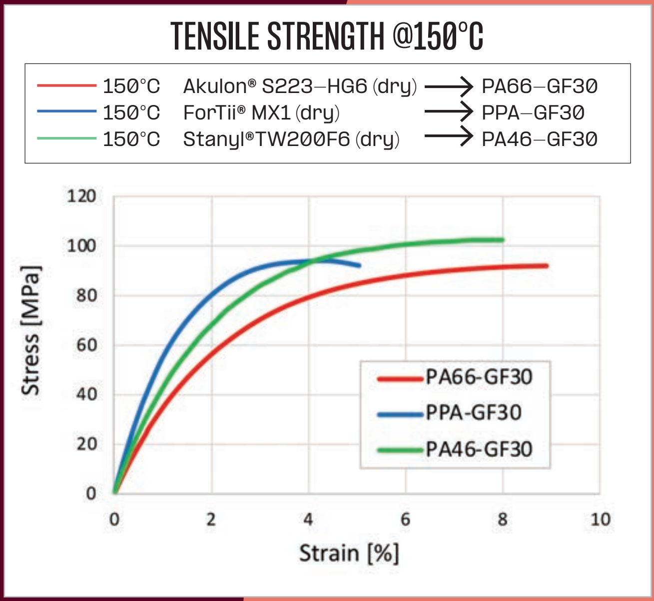
OEMs are further increasing powertrain efficiency, as well as battery capacity and size, to increase the vehicle's driving range. The latter usually leads to a significant increase in the vehicle curb weight, often resulting in poor efficiency when the vehicle's energy consumption is measured in terms of kWh/km. To effectively control and reduce the vehicle's weight and to further increase the driving range, vehicle designers are employing both low weight and high-performance plastic materials and are downsizing future designs.

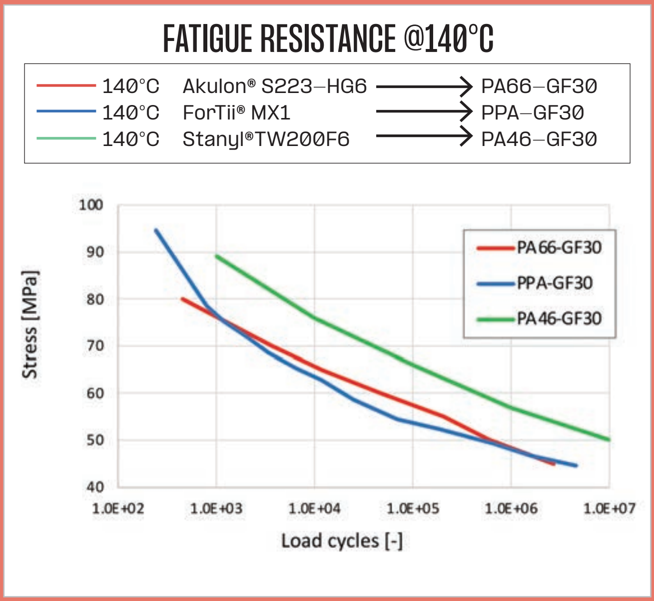
REDUCING CO2 AND PARTICLE EMISSIONS

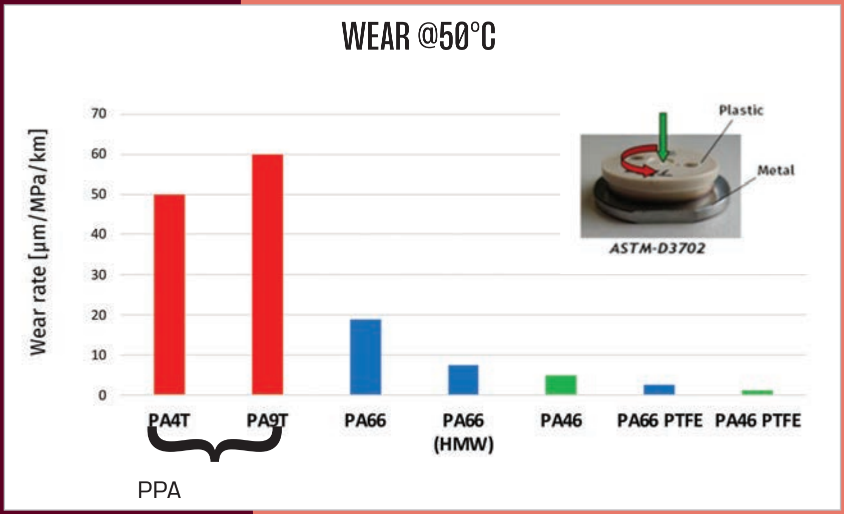
With the industry's ongoing transition to hybrid vehicles and EVs, Envalior has been strongly supporting the automotive industry's needs with CO2 and particle emission reduction.

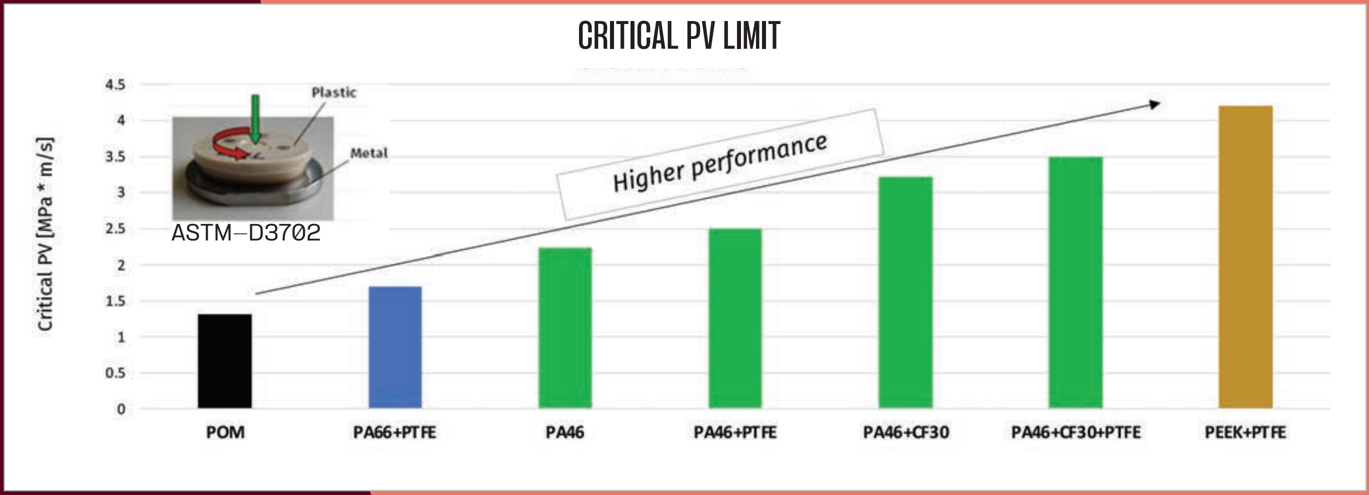


Envalior material portfolio for automotive applications









Properties comparison of Stanyl® PA46 with other engineering polymers commonly used in gears

With its extensive material portfolio, Envalior focuses on supporting the automotive industry with solutions for reliability and performance, weight reduction, packaging space savings and cost optimization.

Envalior materials have a broad range of polyamides (PA6, PA66, PPA, PPS, PA46 and PA410), polyesters (PET & PBT), and thermoplastic elastomers. These high-performance materials are used in automotive structural parts, tribological components and in NVH-sensitive applications.

AN OPTIMAL MATERIAL FOR COMPACT, DURABLE, LOW WEIGHT AND LOW NOISE GEARTRAIN DESIGNS

Stanyl® is a market-leading polyamide 46 extensively used in demanding actuator geartrain applications. It offers exceptional mechanical and tribological performance, compared to alternative polyamides like polyphthalamide (PPA) and PA66, and it performs well in both dry and under lubricated conditions.

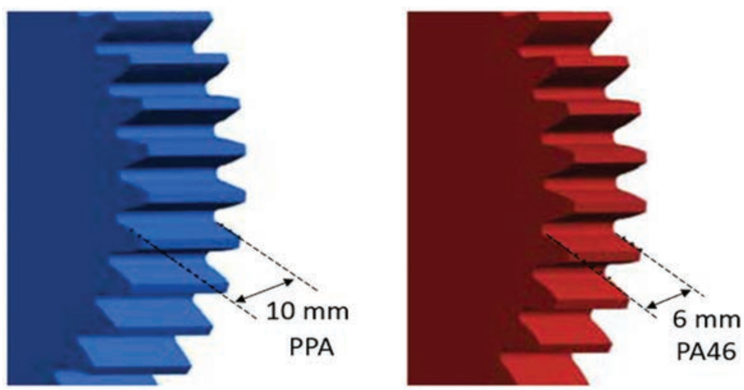
With the highest amide density of all polyamides, Stanyl® has a uniquely high crystallinity level of 70%, enabling best-in-class high-temperature fatigue and wear resistance, which are often the key material properties needed for a reliable and durable geartrain performance.

Compared to other polyamide materials, including both PPA and PA66, Stanyl® has exceptional flow behavior in the injection molding processing. The combination of a highly symmetrical molecular structure, high crystallization speed, and a high crystallinity level enables robust and durable thin-walled components, allowing engineers to reduce component weight and realize more compact and space saving designs without having to compromise on performance.

Combining high flow and high crystallization properties with low wall thickness designs also leads to lower material usage and shorter molding cycles times, which creates potential savings compared to alternative high-temperature plastics, including PPAs.

Stanyl's® high-fatigue and wear-resistance properties make it the optimal material choice for manufacturing compact and thin-walled gear designs suitable for small packaging spaces where demanding torque and lifetime performance are required.

Compared to alternative materials like polyoxymethylene (POM), Stanyl® demonstrates higher static tensile and fatigue strength, wear resistance, creep resistance and limiting PV performance. The latter property is attributed to Stanyl's® significantly higher temperature capabilities compared with POM (e.g., melt temperature of 295°C [563°F] vs 175°C [347°F]). This quality enables robust behavior in cases where frictional tooth heating effects are posing material limitations from a mechanical, tribological or thermal performance perspective.



Gears made with Stanyl® have the potential to reduce gear width by up to 40% compared to PPA, enabling higher torque and durability performance output per unit weight [Nm/kg], unit space [Nm/m3] and unit cost [Nm/$]

Depending on an application's operating conditions, Stanyl® gears are known to achieve similar torque and lifetime performance levels with up to 40% less material usage compared to alternative high-performance plastics. This characteristic enables significantly lower weight and more compact geartrain designs compared to those made of alternative engineering polymers like PPA, PPS, PA66 and POM.

TORQUE AND DURABILITY PERFORMANCE

Envalior has continuously been investing in material solutions that further evolve plastics performance. Over the years, Envalior has been putting significant efforts into polymer topics related to high- temperature performance, fatigue behavior and wear resistance. These three material properties are commonly correlated with observed failure modes in plastics gear applications.

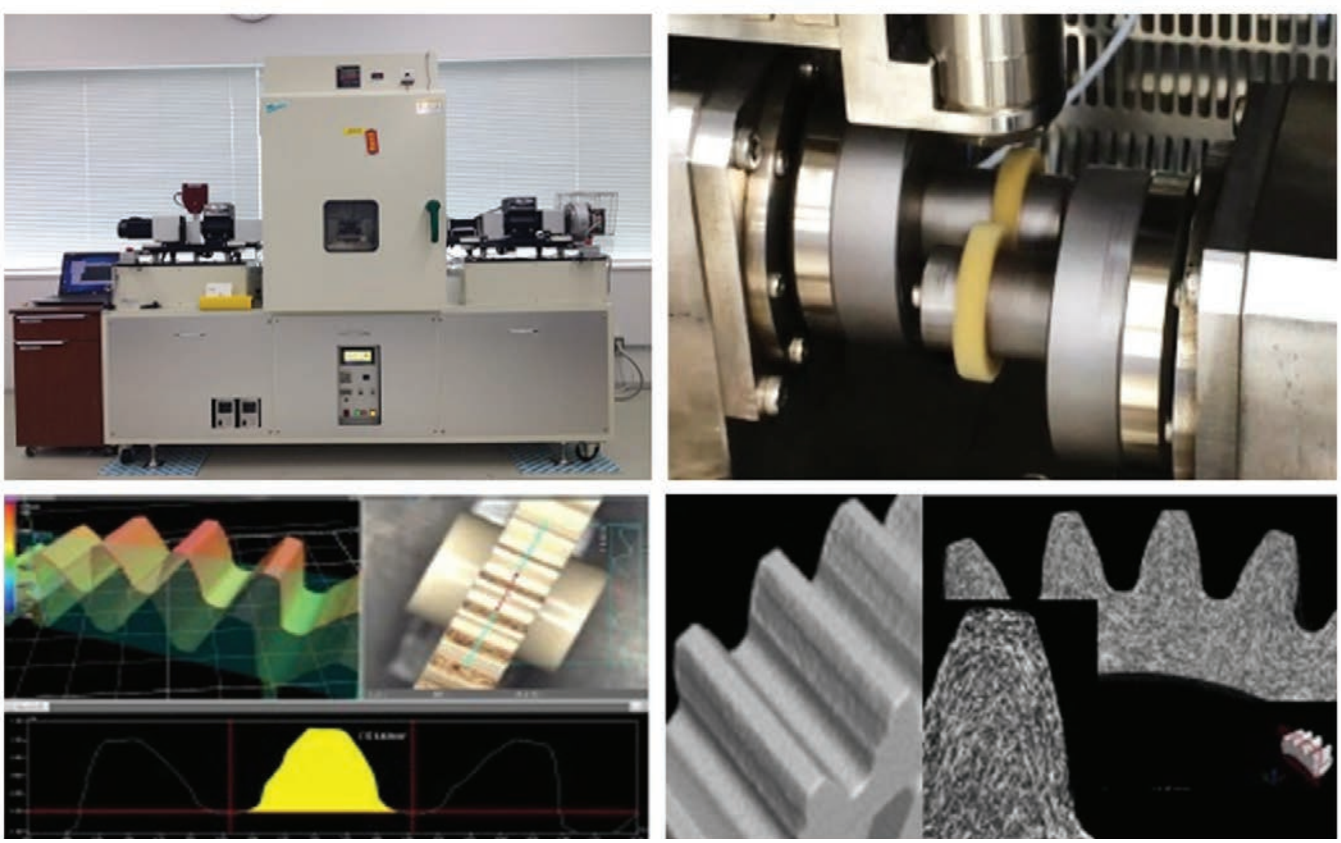
To confirm the performance of plastic materials in injection molded gear components, Envalior uses an internal gear tester.

In addition to benchmarking the performance of different plastic materials used in gears, fundamental plastics-related topics that are known to influence gear performance have been within the scope of Envalior's long-term gear research. This includes parameters such as the fiber reinforcement, fiber type, fiber content level; filler related topics, such as W&F optimizers; grease lubrication effects; and other topics.

The findings from these studies, combined with the observations gathered with customers, enables Envalior to hone into the best performing material grades for a given application and its specific set of requirements. This knowledge helps customers to reduce the number of design iterations and validation trials required to qualify and approve new designs. The latter has proven helpful in shortening overall development cycle times and reducing overall development costs.

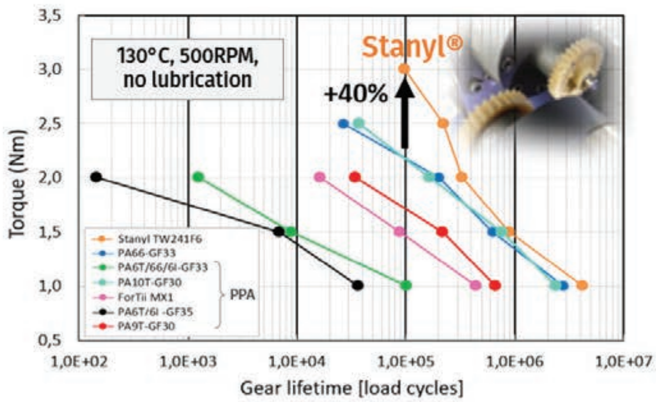
Envalior R&D activities are based on a fundamental understanding of polymer behavior during relevant operating conditions and by deploying the latest state-of-the-art virtual engineering simulation tools, e.g., KissSoft®.

We employ nonlinear finite element analysis (FEA) for the more challenging plastics-related gear topics, where available commercial, semi-numerical gear design tools are not sufficiently suitable. For example, current state-of-the-art industrial gear calculation standards (e.g., VDI2736 and similar) are still under development, so they can't be used

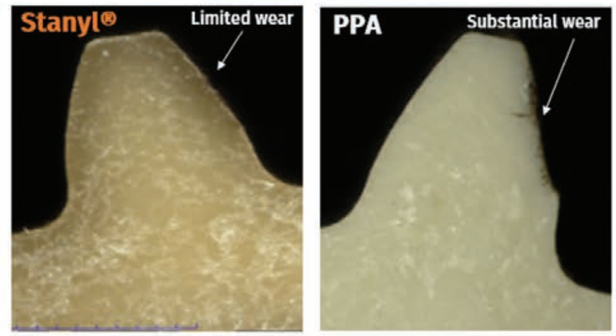


In-house gear test rig is used to evaluate the torque and lifetime performance of injection molded polymer gears

GEAR DURABILITY TESTING



GEARS AFTER TESTING



Tooth wear development after 5 mln load cycles

Gear durability performance of Stanyl® PA46 and several other engineering polymers

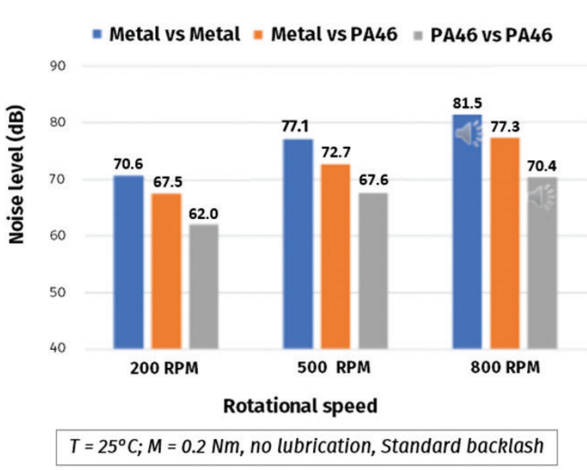
to accurately predict tooth stress levels in a plastic worm gear pair. However, Envalior has the knowledge and capability to provide an accurate assessment of tooth stress levels in this case.

NOISE REDUCTION POTENTIAL

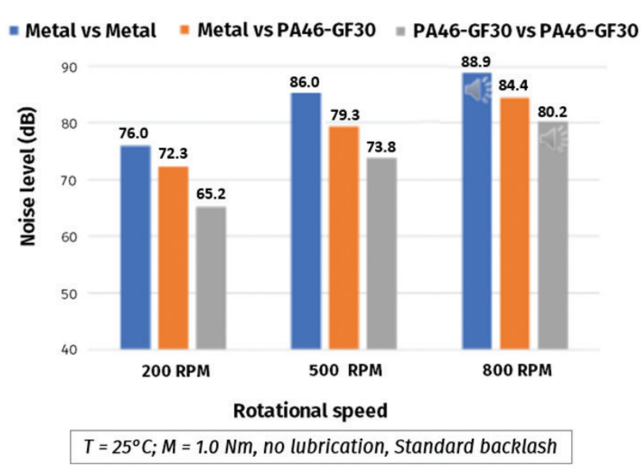
One of the most important drivers for plastic gears vs. metal gears is the need to reduce operating noise, for example, in automotive actuators used for EVs. Envalior is investigating the mechanisms that influence plastic gear noise behavior from both a material and design perspective. Several topics include the type of materials used (e.g., plastics vs. metals), as well as the potential mechanisms and differences between various plastic solutions. This includes factors such as polymer type, fiber reinforcement type (glass fiber, carbon fiber and other fillers) and material damping effects.

Furthermore, Envalior is looking into design and gear manufacturing related topics focused on gear accuracy and backlash performance, including how these parameters could be best optimized to maximize the noise reduction of plastic gears compared to metal gears.

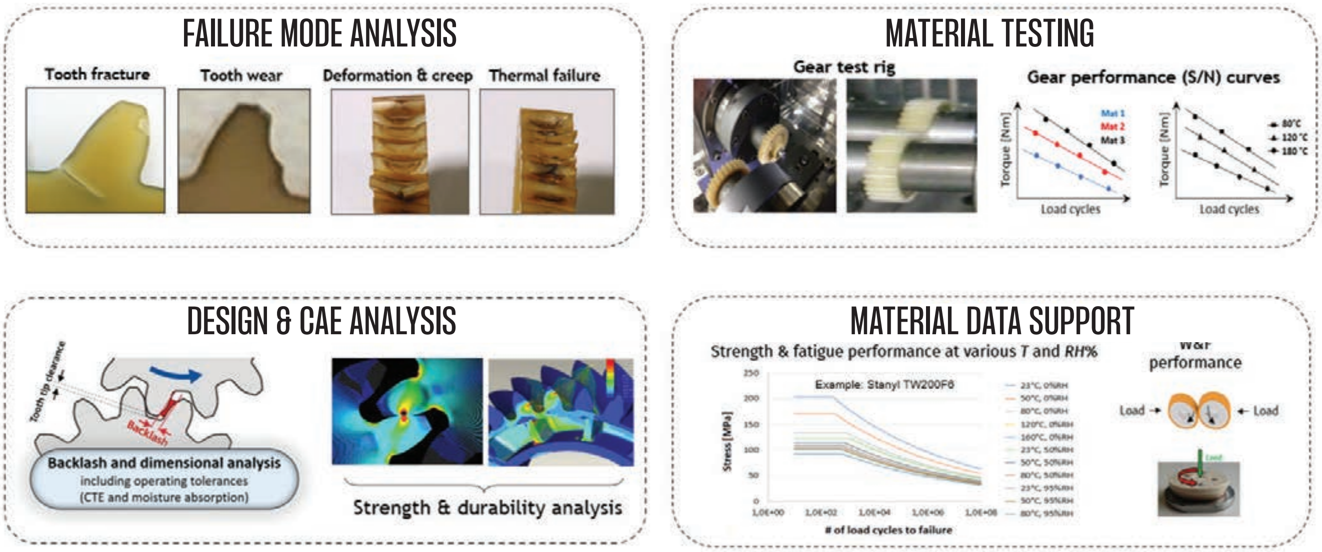
STANYL® TW341



STANYL® TW241F6



Gear noise measurements with Stanyl® TW341 and Stanyl® TW241F6 as a function of gear rotational speed, including a comparison with the gear noise levels generated by a metal–metal gear pair



Envalior leverages material and design expertise to support new customer developments

Observations indicate significant gear noise reduction potential with several of Envalior's grades, for example, Stanyl® TW341 and Stanyl® TW241F6. Depending on test conditions, the observed noise reduction with a Stanyl® PA46 gear pair amounts up to 10 dB compared with an equivalent metal-metal gear pair.

Envalior will continue gear noise-related research focusing on mapping out detailed gear noise behavior vs. relevant operating conditions and parameters. This includes the effects of operating torque levels, temperature, and lubrication conditions, as well as gear design and gear accuracy related effects. The latter includes the effects of gear tolerances and backlash on noise behavior and emitted noise levels.

MATERIAL SOLUTIONS FOR ACTUATOR HOUSINGS AND COVERS

In addition to Stanyl® (PA46) materials used in actuator geartrains, Envalior has been deploying its broad materials portfolio for structural actuator components, including actuator housings and covers. Envalior's extensive material portfolio consists of Akulon® (PA6 and PA66), Arnite® (PBT and PET), Xytron™ (PPS) and ForTii® (PPA). These materials can be used in tandem with Stanyl® for high torque density gear-trains. Envalior has been supporting customers in the development of structural actuator components, aiming to achieve the best possible balance of performance, weight, packaging space and cost.

PARTNERING FOR THE PRESENT AND THE FUTURE

Combining its broad material portfolio and plastics design and engineering expertise, Envalior supports customer developments in geartrain and structural actuator components. Envalior continues to partner with customers across the automotive value chain to improve reliability and performance, while increasing overall cost effectiveness.

Envalior's portfolio includes a wide range of polymer families optimized for performance and cost to meet specific application needs. Material solutions are backed with extensive research and development, as well as collaborative partnerships where Envalior supports the industry through grade selection, plastic design, and via material testing.

With manufacturing facilities on three continents and vertical integration in the monomer precursor to polyamides, Envalior offers a security of supply that gives customers peace of mind, comfortable in the knowledge that material supply will never be an issue. Contact Envalior today to discuss how Envalior can support your current or future developments.

To learn more, contact us at www.envalior.com/contact or visit www.envalior.com

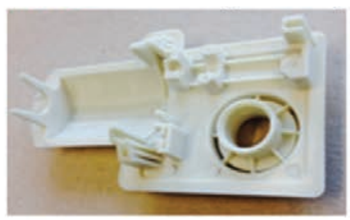
COVER
ForTii® MX2 (PPA–GF30)

HOUSING
Akulon® S223–KG6 (PA66–GF30)

COVER
Arnite® TZ6 280 (PBT–GF30)

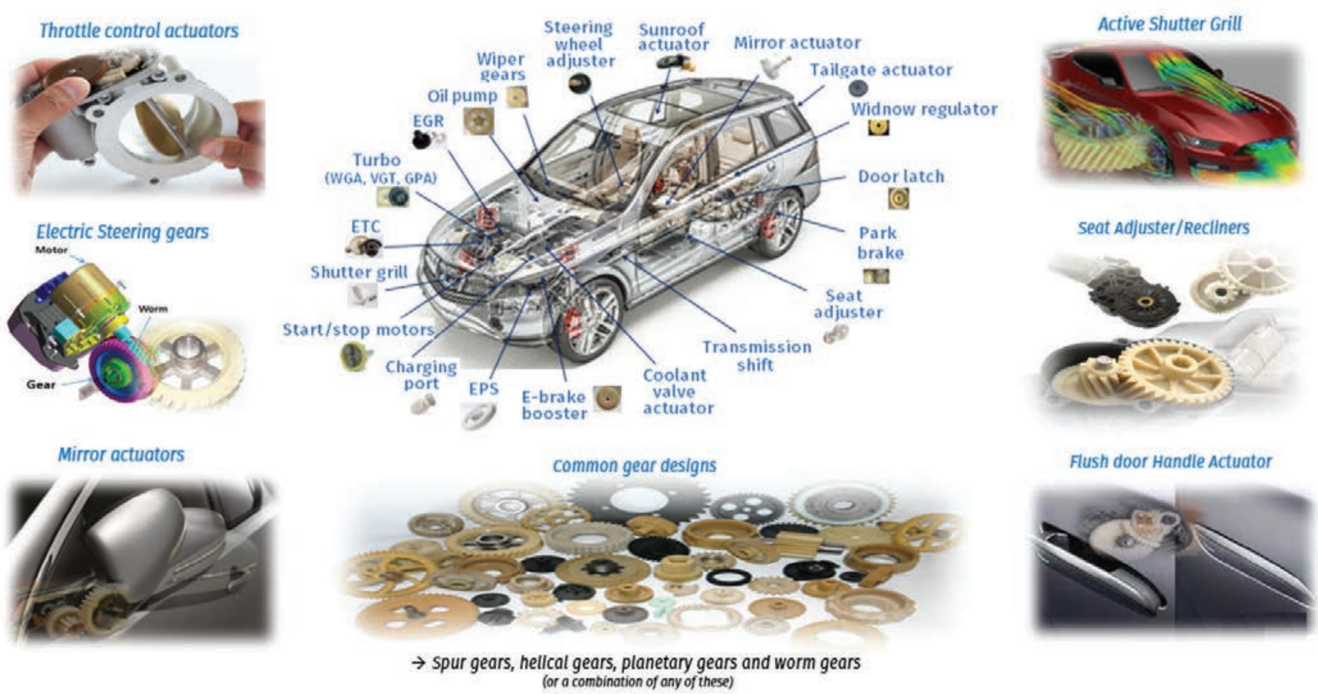
HOUSING
Arnite® AV2 375 XT (PET–GF35)

COVER
Arnite® AV2 375 XT (PET–GF35)



COVER
Xytron™ G4024T (PPS–GF40)

Examples of actuator housings, covers and materials used



Examples of automotive actuators, housings and covers made with Envalior materials for the highest torque performance per unit weight [Nm/kg], unit space [Nm/m3] and unit cost [Nm/$]

ENVALIOR – IMAGINE THE FUTURE

Envalior is a leading global engineering materials solution provider with about 4,000 employees worldwide. With a 100-year track record of customer-focused innovation, Envalior For more information visit www.envalior.com.rtise on sustainable high-performance solutions. The company supplies many of the world's key markets including automotive and new mobility, electronics and electrical, and consumer goods. For more information visit www.envalior.com.

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