The heat shield in the air intake of a Daimler-Benz 4-cylinder automobile diesel engine consists of an innovative heat-resistant polyamide

(figures: BASF)

Charge-Air Ducts in Modern Engines

Polyamides. High temperatures and pressures, as well as attack by chemical substances push the engineering plastics used in modern engines to their limits. In addition to the classic loads, even higher temperatures and, most of all, potential acid attack results from exhaust gas return and turbocharging. Are the materials up to all this? This article provides an answer.

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Legislative requirements for limiting vehicle emissions have tightened repeatedly in recent years: The new Euro 6 norm for trucks will become effective all over Europe in 2013, and for automobiles in 2014. It requires even tougher restrictions on nitric oxide (NO_x)- as well as hydrocarbon (HC) emissions and soot (PM) from trucks. A restriction is being introduced on the quantity of soot and amount of particles from gasoline driven automobiles with fuel injection, while nitric oxide and hydrocarbons from diesel driven automobiles will be reduced even further. Moreover, legislation has opened the market to alternative fuels. Among these are biodiesel fuels, which can be admixed to mineral oil-based diesel fuel up to 7 % in Europe and up to 20 % in the USA, as well as bioethanol that can be admixed to gasoline up to 5, 10 or 85 %. And finally, there are national limits on the sulfur content permissible in diesel fuels that can reach as low as 15 ppm. Unfortunately, in some countries – especially in Africa and South America – the sulfur content is quite high, 5,000 ppm and even higher. Thus the United Nations has assumed the task of aiding these countries in realizing environmental projects, e.g., the reduction of sulfur content in fuels.

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Reducing Pollutants

The automobile industry has a threefold response to the requirements placed by →

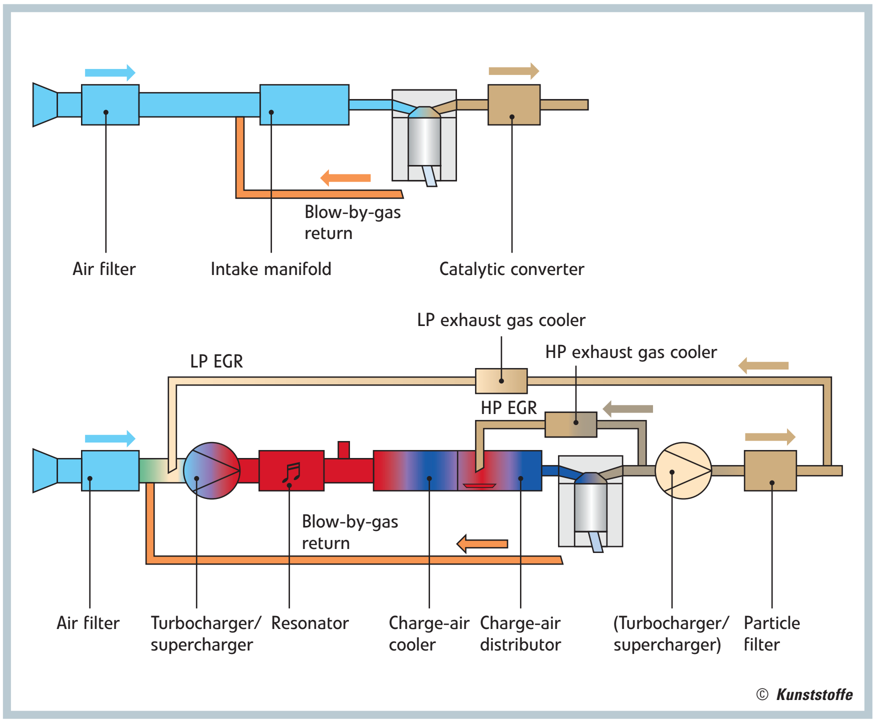

Fig. 1. Schematic illustration of the air, blow-by-gas and exhaust gas passages in a classical aspirated engine (above) and in a turbocharged diesel engine (below)

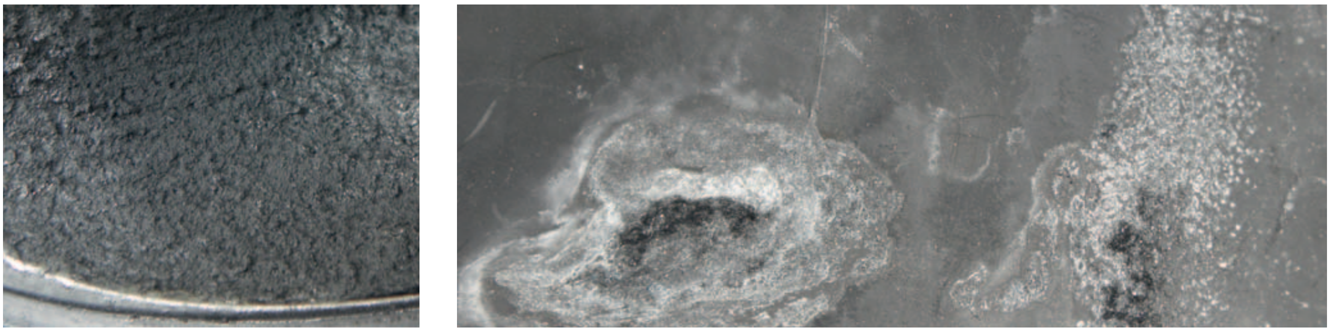

Fig. 2. Soot deposits in a polyamide charge-air duct after 30,000 km in short trips (left), possible surface defects (right)

Euro 6 specifically on diesel engines. Inside the diesel engine, the amount of nitric acid can be reduced by exhaust gas return (EGR): The returned inert exhaust reduces combustion temperature and with it the amount of occurring nitric oxides. Outside the engine, catalytic converters and particle filters serve to reduce NO_x- and soot particles. Finally, downsizing – that is, the use of smaller and lighter engines – reduces vehicle weight. However, in order to maintain performance levels, the gas has to be highly compressed by so-called turbochargers or superchargers in the engine compartment that heat it up strongly. Charge-air, blow-by-gas ducts and EGR are shown schematically in **Figure 1**.

Whereas in a classical carburetor engine, only a small amount of the so-called blow-by-gas from the crankcase housing is returned to the intake system **(Fig. 1 above)**, modern turbocharged diesel engines with high- and low-pressure EGR make very different demands on air passages and consequently on the materials used for them **(Fig. 1 below)**. The low-pressure (LP) EGR flow picked up behind the soot filter and returned via a cooler upstream from the turbocharger is not only relatively cool at 160°, but also largely soot-free. However, at these low exhaust temperatures, aggressive mixtures of nitrogen and sulfur oxides can form, affecting the component parts of those air passages. For any materials in the area of charge-air passage, the high-pressure (HP) EGR flow picked up right behind the engine compartment creates even bigger problems, especially in turbocharged diesel engines, since it contains large quantities of soot whenever combustion is not complete, as in city traffic. Via this HP exhaust gas return, soot particles get into the charge air and thus enter the charge-air distributor.

A charge-air distributor can be seen in **Figure 2 left**, on the inner wall of which a soot sponge has formed after 30,000 km of short-distance trips. The resulting condensate of nitric and sulfuric acid can build up easily here. This is hard to purge from the sponge and thus attacks the surface. The problem therefore arises due to

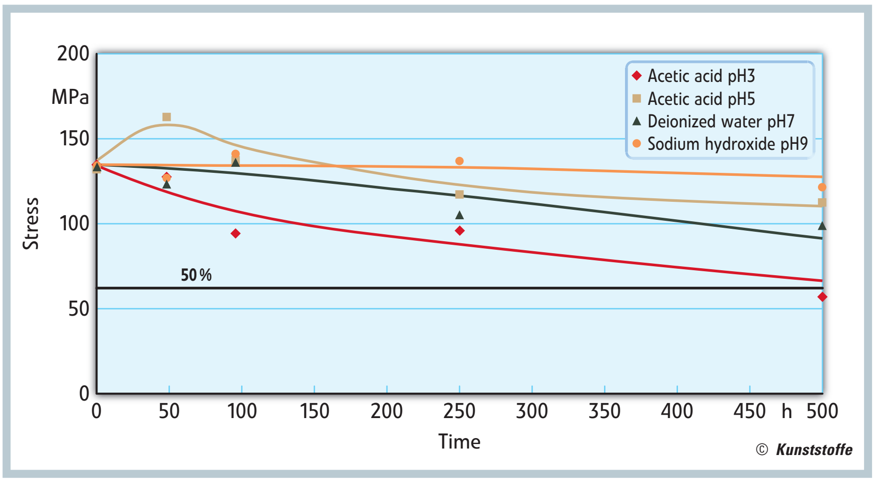

Fig. 3. Statistical chemical resistance test on Ultramid Endure D3G7 at various pH-values (storage temperature: 100 °C)

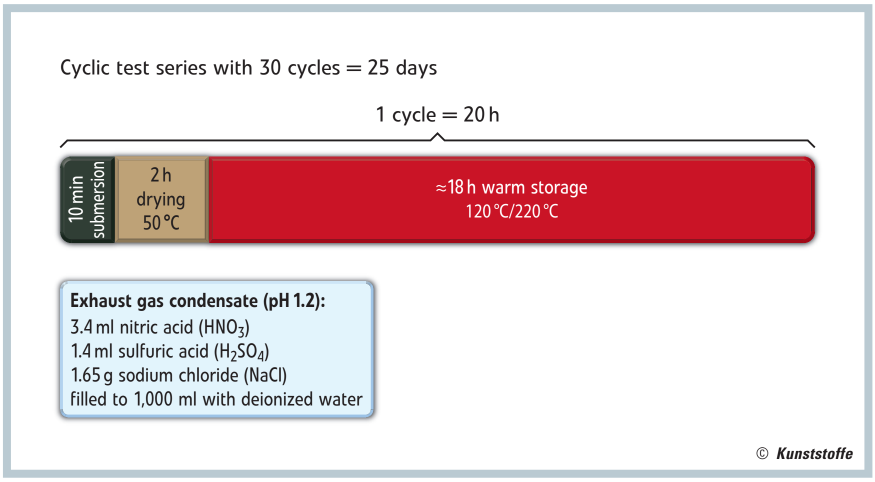

Fig. 4. Cyclic test of plastics samples by analogy to VDA 230-214

a combination of hot soot and simultaneously returned acidic exhaust gas. This worst case, a very aggressive chemical ambience, can only arise in this air passage segment if the sulfur content in the fuel is high – which is not the case in most industrialized Western countries – and a turbocharged diesel engine with EGR also has to deal with many short-distance trips that lead to incomplete combustion. Only under these unfavorable conditions does the combination occur, consisting of high pressures and temperatures, a high soot content capable of collecting fluids in spongy structures, and the formation of sulfuric acid in addition to nitric acid.

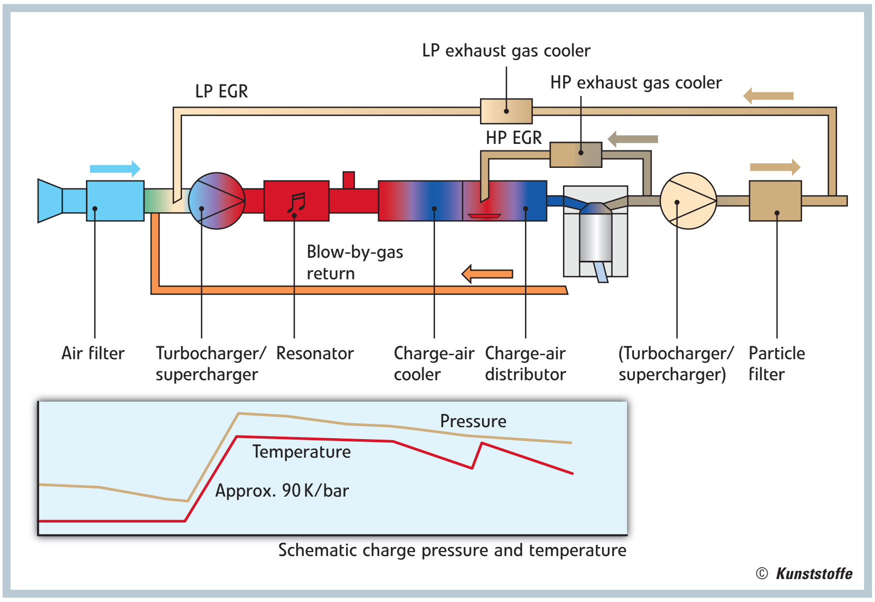

Fig. 5. Downsizing: Schematic pressure and temperature curve of a turbocharged engine

Heat and Chemical Resistant

Exhaust gas return in modern engines has thus brought about progress in the chemical and thermal resistance of materials used for charge-air passages. The effect of condensates on these components depends not only on the concentration and temperature of condensates, but also on the duration of their influence. Once the soot sponge is removed, damage to a polyamide can then look like it does in **Figure 2 right.** Given unfavorable conditions, this surface defect results after only a few thousand hours of operation. Pitting corrosion, such as occurs in aluminum and aluminum alloys, does not occur in plastics.

In order to recreate such real and complex conditions in the engine for test purposes, materials developers and vehicle manufacturers have drawn upon different testing methods. In statistical tests, the material is stored in acids (usually easy-to-handle acetic acid) with defined pH-values at a definite temperature over a definite period of time. Subsequently, mechanical properties, such as fracture stress, are measured according to ISO 527-2: 1993. The result of such a statistical measurement is shown in **Figure 3.** The currently most heat-resistant polyamide available from BASF SE, Ludwigshafen, Germany, Ultramid Endure, retains 50 % of its original strength after 500 h storage in an acid with a pH-value of 3. Ultramid Endure is the currently most efficient temperature resistant material for application in engines with up to 220 °C continuous temperature. However, it must be kept in mind that such statistical tests do not illustrate actual cases very well: In reality, the plastic is not constantly submerged in acid, acid concentration varies, and the temperature regularly falls back below room temperature.

By contrast to statistical tests, cyclic tests attempt to recreate the more reality-oriented shifts between loading and unloading. For metal parts, there exists the defined testing standard VDA 230-214. Tests analogous to this standard were performed together with a vehicle manufacturer according to the scenario shown in **Figure 4**; however, no change was found in the mechanical behavior of Ultramid Endure. Here, OEMs and plastics manufac- →

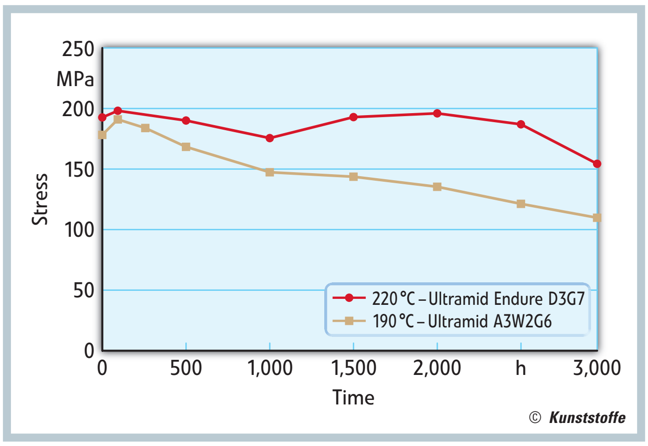

Fig. 6. Materials for downsizing highly charged engines

Fig. 7. This charge-air duct for truck engines is made from heat-stabilized polyamide, replacing a significantly heavier metal one

turers have to jointly work out near-real, yet sufficiently safe test instructions. In this connection, it would be helpful to draw comparisons with existing classical materials for charge-air ducts, e.g., aluminum.

The Ultramid Endure D3G7 introduced at the 2010 plastics fair has found an especially interesting serial application in 2012 as a heat shield **(Title photo)** downstream from the EGR in a Daimler-Benz 4-cylinder automobile diesel engine at the point of introduction for high-pressure exhaust gas flow, i.e., at a very critical point in the charge-air passage. Thanks to its 220 °C temperature resistance in continuous use and 240 °C peak load, this material can be used in all components downstream from the turbocharger: that is, at the resonator, in the charge-air ducts, for sensors and actuators, at the intake of the charge-air cooler and in the charge-air distributor (previously: intake manifold) **(Fig. 5)**. BASF is now working on a version of Ultramid Endure that is specifically suited for blow molding (charge-air) piping.

Ultramid A3W2G6, whose continuous working temperature of 190 °C lies somewhat below that of Ultramid Endure **(Fig. 6)**, has already found serial application **(Fig. 7)**. Detroit Diesel of Detroit, Michigan, USA, is currently using this version of the material at the point of introduction for HP EGR – in this case in the DD12 and DD15 engines.

Conclusion

BASF's polyamide palette meanwhile includes two materials suitable for use in highly turbocharged engines.

Most important is the fact that the Ultramid Endure tested as described here has not only proven itself under high temperatures, but also exhibits good resistance to acids up to a pH-value of 3 in the tough statistical test. To be sure, neither the statistical, nor the cyclic acid test is standardized and certified. If the vehicle manufacturer utilizes a heat-resistant plastic with a favorable price/performance ratio, such as Ultramid Endure or Ultramid A3W2G6, in the vicinity of a charged engine, then it still has to rely on tests of actual components. ■

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