Friction reduction: a Hot Topic

(English translation of publication in Technische Kunststoffe 10/2012

Author:
Jippe van Ruiten - DSM Engineering Plastics

In the automotive industry, fuel economy improvement is critical – which is where plastics can make a real difference. To maximize the potential benefits that materials can bring, you need a deep understanding of the application. In this paper we demonstrate just that: How plastics can help to reduce friction in the timing chain system cost effectively.

Introduction

The major drivers for most trends in automotive today are quests for lower total cost of ownership by consumers and for higher profitability levels (lower system costs) by the OEMs and Tier1s. Green solutions (lower emissions, reduced fuel consumption, better recyclability, smaller carbon footprints) are required to bring more sustainable automotive mobility. Some of these needs are reinforced by specific governmental regulations and legislation regarding CO_2, NO_x and particulates emissions according Euro V and Euro VI, use of biofuel, ELV directive and others. solutions are found in weight-down (metal replacement), performance-up (downsizing, friction reduction) and in bio-based materials.

In line with the company's leadership position in the DowJones Sustainability Index for many years, DSM innovations are driven to facilitate these industry needs. An example is the way DSM has applied its biotechnology to produce 2Gen Biofuels such as Ethanol from cellulosic biomass coming strictly from outside the food chain [1]. Examples of developments in plastics for automotive are numerous. To name a few: DSM recently introduced PA410 (tradename EcoPaXX ™) [2]. , an aliphatic polyamide based on diaminobutane and sebacic acid. EcoPaXX ™ is a green, bio-based material: the polymer consists for ca. 70% of building blocks derived from renewable resources, i.e. castor oil. Since castor beans are grown on arid soil unsuited for growing crops, it is not in competition with the food chain. EcoPaXX ™ PA410 combines mechanical properties in the range of PA66, but with lower moisture absorption (dimensional stability) and better chemical and hydrolysis resistance. Typical application examples are fuel connectors, engine cooling parts and oil sumps. Its impressive surface quality has made it successful in engine covers.

In weight saving, one of the most pronounced metal-to-plastic-conversion developments in thermoplastics is that of oil sumps and pans for passenger cars. Depending on the design, weight can be reduced by 20-50% (up to 1.5 kg) when switching from aluminium and/or steel to

PA6 or PA66. In cooperation with several Tiers and OEMs, various designs in PA6 have been optimised with regards to strength and stiffness, NVH and stone impact. Here DSM's cutting edge CAE modelling techniques in conjunction with relevant application tests are key for joint success.

The trend towards downsizing of engines implies the use of more and more turbo charging. Depending on the actual boost pressure, temperatures can raise up to 220°C. In order to cope with these temperatures for 5000 hours and longer, DSM was the first to develop a special material technology (PA46 Stanyl Diablo) [3]. It has been approved already for various turbo parts as charged air ducts and resonators Fig 1.

Figure 1; Integrated duct and resonator in Stanyl Diablo, directly bolted onto the turbo.

Friction reduction in engines

In modern engines, as much as 25% of the work available at the pistons is lost in internal friction in the engine. Obviously there is much focus on reducing these parasitic losses. DSM's products are facilitating such improvements. One example is Mahle's Low Friction Camshaft, that is able to improve fuel economy by 1 – 1.5% Figure 2. [4]

Figure 2; Stanyl used in the bearing cage of the needle bearings pre-assembled to the Low Friction Camshaft.

A very specific contribution in friction reduction has been realised in the timing chain system. Working in close collaboration with OEMs and Tiers DSM has been able to demonstrate that by changing the wear surfaces of the guides and tensioners from PA66 to Stanyl PA46, the friction torque of the chain drive system can be reduced by as much as 15%. [5].
Obviously the extent of improvement that can be achieved per engine depends on the layout of the timing chain system. To enable a quick assessment of those benefits, we have developed a calculation tool that is also accessible from the web [6]. The calculation provides an elegant breakdown of the contributions to the overall friction in the chain system. The majority of friction arises from contact between the chain and the plastic wear faces as is illustrated in figure 3.

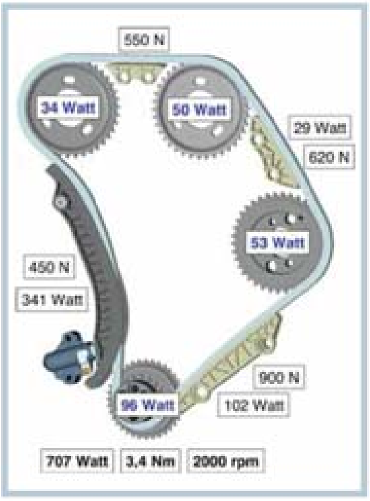

Figure 3; A timing chain layout with parasitic loss contributions due to sliding friction and chain articulation.

There is fairly general consensus that the friction between chain and wear face occurs in the mixed or boundary regime [7]. Detailed analyses on test engines have shown that the typical Stribek curve response is due to the journal bearings on the camshafts and crankshaft. The remaining contribution, due to chain on plastic, is not really speed dependant. Moreover it has been shown that with increasing oil viscosity, the chain-on-plastic friction reduces, which is consistent with mixed or boundary lubrication. Also our idealised, more fundamental assessment of hydrodynamic lift as function of speed, oil viscosity, surface roughness and guide radius, reveals that even for fairly straight guides, the hydrodynamic lift is insufficient to establish an intact oil film at realistic chain tension. This is illustrated in figure 4. It is essential, because only then a direct contact between metal and plastic occurs and thus the plastic type can affect the level of friction.

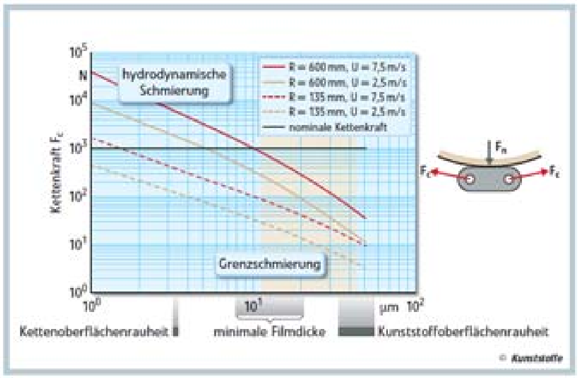

Figure 4; Lubrication regimes for chain-on-guide. Boundary lubrication occurs when the chain force is above the drawn curves.

At DSM the in-engine friction conditions were mimicked as closely as possible on a thrustwasher type Tribometer. The coefficient of friction (CoF) of several materials was measured in engine oil, Figure 5. These measurements confirm a 20 – 30% lower CoF of PA46 (Stanyl TW341) versus PA66 grades commercially used in chain tensioners and guides. Even a more exotic friction-optimised PA66 based material recently introduced in the market does not show a lower CoF than Stanyl in our test.

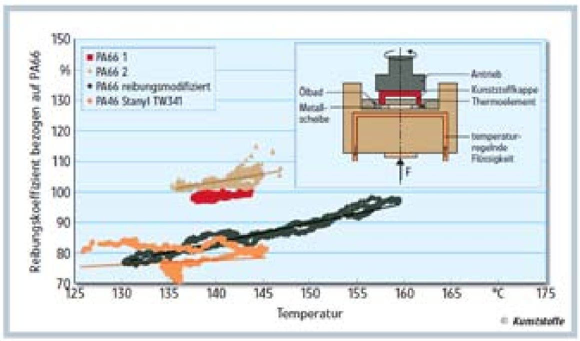

Figure 5; Graph comparing CoF of several materials versus temperature.

The main differences in tribological behaviour between PA66 and PA46 find their origin in the intrinsic mechanical properties. The modulus of a material at the in-use temperature is a key indicator since it measures the resistance against small scale deformations. Since Stanyl has a higher crystallinity, the modulus above the glass transition is some 30 – 40% higher as can be seen in figure 6. This means that the metal asperities (peaks on the surface roughness) cannot penetrate as deeply into the Stanyl as they can into the PA66. This smaller interaction explains the observed lower friction. The higher crystallinity also provides the basis for the observed better wear resistance.

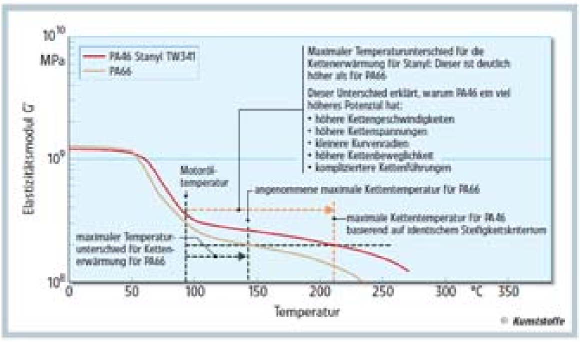

Figure 6; Modulus versus temperature of PA66 and PA46.

Figure 6 also illustrates how Stanyl is better able to cope with higher PV systems (i.e. hotter chains). For the sake of argument, let us assume that 140°C is the absolute maximum chain temperature that PA66 chain guide can sustain. The red horizontal line in fig. 6 then indicates the level of modulus at the friction interface with the timing chain. This same level of modulus can be provided by a PA46 wear face at roughly 210°C. Taking the oil sump temperature of 90°C as the heat sink temperature, timing chains with PA66 guides can only accommodate chains that are 50°C hotter than the oil. Stanyl guides however can sustain chains which are about 120°C hotter than the oil. This is over a factor 2 larger delta T as PA66.

As illustrated in figure 3, the amount of energy lost in friction can easily be several 100 Watts. All this heat is liberated in the chain and causes the chain to heat up. It is possible to estimate the nominal chain temperature from the cooling capacity due to convection to air, oil and conduction to the sprockets. We have validated these calculations experimentally using IR Pyrometry [8] and confirmed that the average chain temperature can easily be some 30 – 40°C above the oil sump temperature.

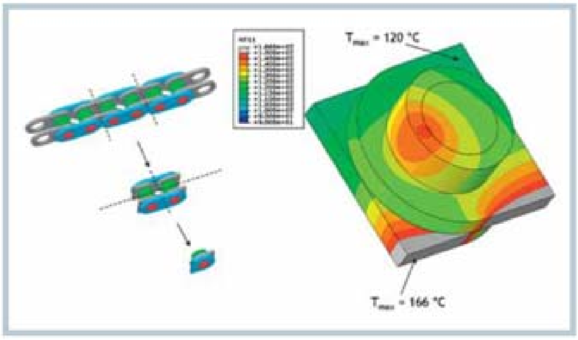

Figure 7; 3D dynamic thermal modelling reveals considerable local overheating at the chain to guide contact.

Our detailed dynamic 3D thermal modelling is illustrated in figure 7. It takes into account the pulsed heating of a chain element due to chain articulation and sliding friction as well as pulsed cooling due to oil jets that are lubricating the chain. Results reveal that there is a significant local overheating at the sliding contact area. The high thermal conductivity in the metal chain is insufficient to even out the local heating and cooling pulses. In extreme cases, this can lead to overheating and melting of the plastic in the contact area.

The low thermal conductivity of plastics makes it difficult to measure such local high temperatures. One option is to include a thermocouple wire in the plastic, close to the surface. The inclusion of a highly thermally conductive thermocouple wire in the plastic body will, however, lead to significant deformation of the temperature profile as shown in figure 8. It is therefore possible to see melting at the plastic surface, while the thermocouple only indicates 150°. Although accurate absolute measurements are difficult, one can observe a 5 – 10°C lower plastic temperature in Stanyl guides compared to PA66 under similar conditions. This again confirms the lower friction of Stanyl PA46.

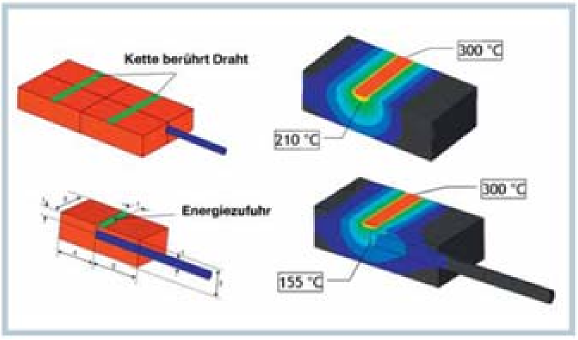

Figure 8; 3D dynamic thermal modelling reveals how the temperature profile in a plastic is distorted by introducing a thermocouple.

Conclusion

DSM is collaborating with a growing number of global OEMs and all Tier1s to validate the friction benefit that Stanyl can bring in timing systems. Over half a dozen engines on motored test stands have confirmed a significant friction benefit anywhere between 0.1 and 0.5 Nm friction torque reduction. Changing the wear faces that are in contact with the chain from standard PA66 to Stanyl PA46 is recognised to be the most cost effective way to improve fuel economy in engines. Since Stanyl is known for its superior wear resistance, the friction benefits come at zero risk of any change or re-approval costs, such as would be required for new materials. It simply contributes to building the most robust timing chain systems.

In order to be an innovation leader and to successfully participate as a development partner in the plastics industry, DSM Engineering Plastics is convinced that it is essential to develop a deep insight into the application fields of its key market segments. The company will continue to creatively combine application know-how with expertise in Tribology and Materials Science and extend our materials portfolio.

Literature

[1] www.poetdsm.com
[2] www.dsm.com/en_US/automotive/public/home/pages/press-releases/2010_10_27_biobased_ecopaxx.jsp
[3] www.dsm.com/en_US/automotive/public/home/pages/press-releases/2010_06_21_diablo_utb.jsp
[4] Friction Optimisation and its Effect on Specific Fuel Consumption, Jörg Rückauf; Boris Lerch, MTZ worldwide Edition: 2009-08
[5] Camshaft Drive Optimization, J. van Ruiten, R. Proost, K. Maile, Engine Technology International, January 2011, p66, http://viewer.zmags.com/publication/85bdbbfc#/85bdbbfc/68.
[6] www.tcfrc.stanyl.com
[7] Advanced Engineering Design, Anton van Beek, p. 274
[8] A Pyrometer type IMPAC IPE 140 with sight tube from www.lumasenseinc.com was used.]

Biography

Jippe van Ruiten, born 1960, holds a university degree in Polymer Physics and joined DSM in 1988. Since 2007 he has been responsible for application development in automotive powertrain globally at DSM Engineering Plastics.