Lowering friction with **Stanyl®** in chain tensioner.

In automotive, fuel economy improvement is of highest priority. High performance plastics are an important enabler in making cost effective progress. To maximise the potential benefits that materials can bring, a deep understanding of the application is essential.
In this paper we demonstrate how plastics can help to reduce friction in the timing chain system.

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.

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 4 to 15%.

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 [see www. tcfrc.stanyl.com]. 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 1.

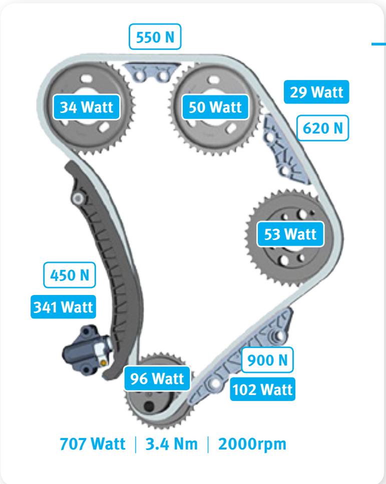

Figure 1. A timing chain layout with parasitic loss contributions due to sliding friction and chain articulation.

There is fairly general consensus that the friction between chain and wear face occurs in the mixed or boundary regime.

Detailed analyses on test engines have shown that the typical Stribek curve response is due to the journal bearings on the camshafts and crankshaft plus the contact between the tappets and the cam lobes. 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 2. It is essential, because only in mixed or boundary lubrication a direct contact between metal and plastic occurs and thus the plastic type can affect the level of friction.

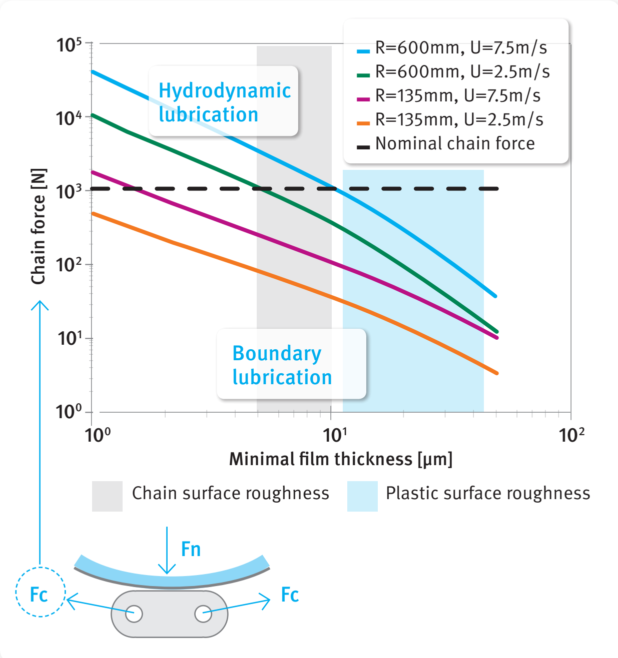

Figure 2. Lubrication regimes for chain-on-guide. Boundary lubrication occurs when the chain force is above the drawn curves.

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 3. 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.

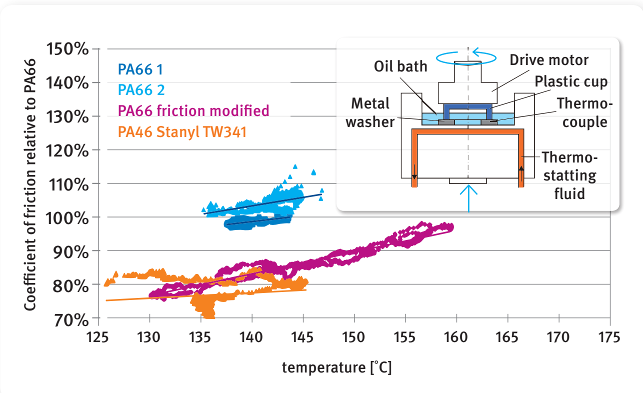

Figure 3. Graph comparing CoF of several materials versus temperature.

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 4. 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.

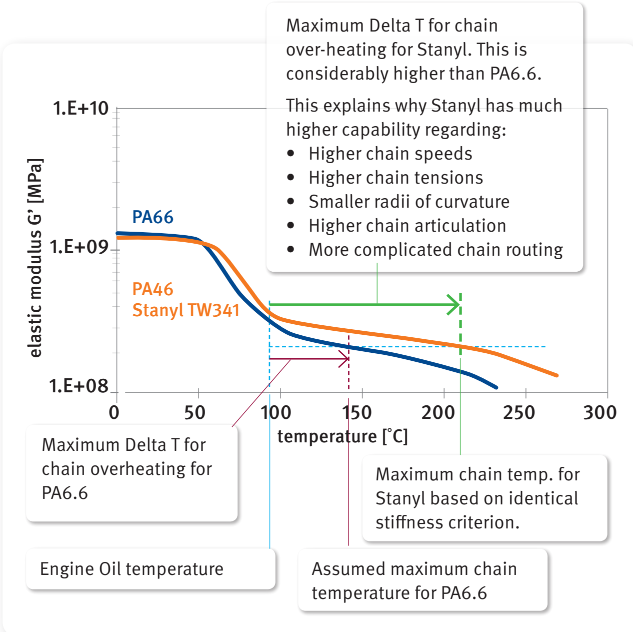

Figure 4. Modulus versus temperature of PA66 and PA46.

Figure 4 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. 4 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 1, 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 and confirmed that the average chain temperature can easily be some 30 - 40°C above the oil sump temperature.

Our detailed dynamic 3D thermal modelling is illustrated in figure 5. 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.

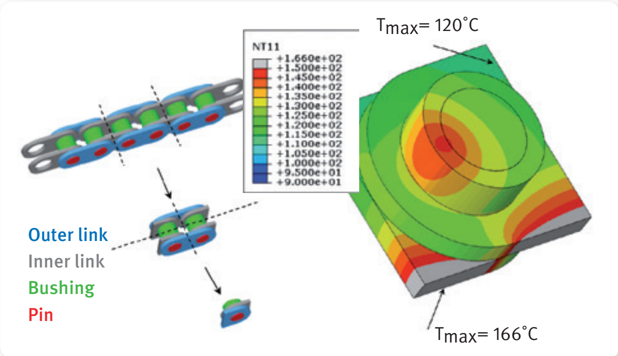

Figure 5. 3D dynamic thermal modelling reveals considerable local overheating at the chain to guide contact.

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 6. 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.

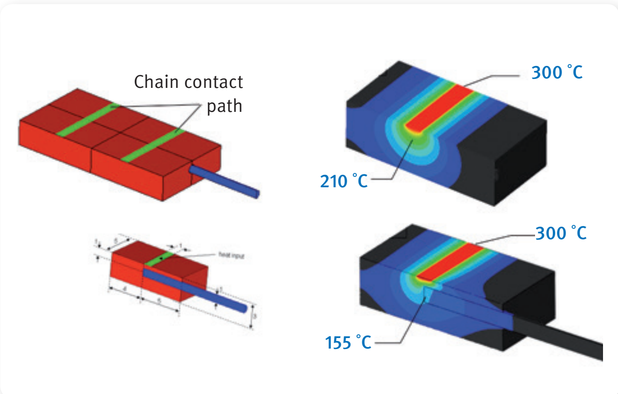

Figure 6. 3D dynamic thermal modelling reveals how the temperature profile in a plastic is distorted by introducing a thermocouple.

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 a dozen engines on motored test stands have confirmed a significant friction benefit anywhere between 0.1 and 0.5 Nm friction torque reduction. The corresponding fuel economy improvement has been measured and confirmed in fired engine tests [Hyundai/BorgWarner, SAE International 2012-01-1752, published 09/10/2012]. 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 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.

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