High-performance polypropylene: does PA 6 still have a future?

Dipl.-Ing. H. Häberle, MAN Truck & Bus AG, Munich

Abstract
If at all possible, lightweighting should be cost-neutral in terms of component costs and investment. Better yet, it would be cheaper and therefore allow additional project costs to be evened out in the event of the component entering current series production. High-performance propylenes (HP-PPs) meet these requirements in a special way, since when swapped out one for one against the corresponding polyamide or polyester blend, the weight of the component falls by approx. 15%. The reduction in material cost associated with this resulting from the lower density is rounded up slightly by a generally lower price per kilogram. Experience shows the volume price to be the decisive reduction variable.
But not only weight and cost efficiency speak in favor of the HP-PPs: reduced CO₂ emissions in all process steps have led us to tackle the replacement of PA6 and pushing forward with this.

1. Introduction
Lightweight construction is an extremely important issue not only for moving masses if requirements such as energy efficiency or fast and precise movements are to be satisfied as perfectly as possible. Even for stationary masses, lightweight construction means among other things lower resource consumption for own production and a lower resource utilization for transportation from A to B.
This circle closes in the case of the truck: on the one hand it must carry lighter in itself, on the other hand, it must be lighter to carry. Both taken together is the efficiency which a CO₂-optimized transport sector requires.
Material lightweighting is often taken today to mean the replacement of metals by suitable plastics since the large difference in density means that correspondingly large reductions in mass can be achieved, provided the plastic satisfies all component requirements. The term then used is the so-called 'metal substitution plastics.'
In the meantime, the so-called high-performance polypropylenes have become a serious competitor for these metal substitution plastics, which normally means the polyamides. Replacing polyamides by HP-PPs in 1:1 substitution generally means a saving of approx.
15% mass. Material utilization costs also fall correspondingly. The HP-PPs are thus pushing at open doors. Given these advantages, implementation on a large scale is only a matter of time.

For the above reasons – CO₂ efficiency, weight efficiency and cost efficiency – we have been working intensively in this area since 2013 and have in the meantime posted some successes in the changeover but also have had to absorb some setbacks. From this we have learnt what needs to be taken into consideration with new developments if the potential of the HP-PPs is to be exploited.

2. Comparison of the properties of HP-PPs and PA-GF60

The components which we wanted to replace in the current bumpers of the Euro 6 series and which are described in the following sections are today still made from PA-GF60 or PBT/PET-GF45. The high-performance PPs had therefore to be measured against the PA-GF60 benchmark – PBT/PET-GF45 is only used in the headlight carrier steel bumper TGS/X and thus ‘ran in the slipstream’ but was not considered further.

![Comparison of the performance of HP-PP and PA](image)

Fig. 1: Comparison of the performance of HP-PP and PA [1]

In the early stages of the project, in addition to the three HP-PPs the PA-GF50, which is used in the foot plate reinforcement of the TGL/M steel bumper, is also compared with the benchmark PA6-GF60. This comparison was made on the basis of 'elongation at break/tensile modulus of elasticity' (Figure 1).

During the subsequent course of the project, more PPs were then included in the comparison (Figure 2). These also included three PP-CF grades with 20, 30 and 40% carbon fiber (12, 13, 14). What is striking about these carbon-fiber PPs is their high stiffness – even their...
density-related tensile strength is in some cases even higher than the benchmark PA6-GF60. If, however, elongation at break is also included in considerations, the picture changes dramatically.

These number games show impressively that the comparison of isolated material characteristic values can lead to errors and does not provide useful information. In my experience, with our high dynamic demands a good balance between stiffness and flexibility (elongation at break) is important in the area of the frame components, of which the bumper is one, if the plastic is not to be 'shattered internally' by the high dynamics.

We have, together with our suppliers, examined and evaluated various HP-PPs with different glass-fiber contents as replacements for the PA6-GF60. Possibilities were PP grades with 50% and 60% glass-fiber content. Our suppliers decided in favor of the Rialene grades SGF50 and SGF60 on account of their better flowability, better processability and greater process reliability. Operating-strength tests, both static and dynamic, were carried out on the TGL/M plastic bumper for both HP-PPs. The environmental qualification process according to our internal standard was also completed. This included a heat and coldness test, a static climate test and the automotive industry's well-known alternating climate test.
3. Structural components in the TGL/M plastic bumper

This bumper, shown in Figure 3, was the first of our four bumper types to be tested on the operating-strength test stand. With this bumper we wanted to test both PP-SGFs thoroughly in order to then decide on one of the two for the other bumpers. This bumper was therefore defined as the reference, since it is comparable with the other bumpers as regards the dynamic requirements but its total shot weight of 14 kg represents the heaviest mass of PA-GF60.

This three-piece bumper consists of the left-hand and right-hand headlight areas, the center section with the step. In the case of these three modules, the panels made of non-reinforced PET/PC thermoplastics are attached to the corresponding carrier components. These load-bearing plastic components are made of PA6-GF60 and screwed onto the die-cast aluminum brackets. These in turn are mounted on the steel front-end cross-member.

![Three-part TGL/M plastic bumper](image)

While both HP-PPs successfully completed the environmental qualification, they were not successful in vibration testing or the static climb-up test. Wear on the mounting lugs was excessive in the case of the headlamp holders and in the holder middle part the bottom chord did not reach the required tread load of 6 kN.

The static climb-up test simulates the load which can occur when the driver climbs up onto the step to clean the windshield.
In this regard it should be mentioned that the components, since they were matched to polyamide, were not designed in some important details appropriately for PP. Modifying the mold was not regarded as worthwhile on account of the low part numbers involved. After completion of all tests and the evaluation of results, we decided in favor of PP-SGF50 and did not pursue PP-SGF60 any further.

3.1 Headlight holders

Due to the high dynamic loads with impulses of up to 15G acceleration in all three spatial directions, even with very little play between the components the effect can arise whereby pairs rub against each other, and this can lead to failure of the components. Wear on the mounting lugs was here so great with SGF50 and SGF60 that the every-increasing play between the side panels and the headlight holders resulted in fracture of the side panels. The small image at top right in Figure 4 shows a mounting lug at the start of testing, while two images below it show lugs when the test was stopped. A small amount of wear was also found with PA6-GF60 but this did not represent a problem. These results show that assemblies must be designed such that components can be installed without any mutual play.
3.2 Beam middle section
With this component the toughest requirement is the tread load of 6 kN (Figure 5). The PPs could here manage only 4 and 4.2 kN, which was quite a way below the 6 kN required — but the difference from the benchmark PA6-GF60 was even greater. Double the value of PP was achieved here. The polypropylenes would therefore have to compensate with somewhat more material and an optimized geometry – with a density advantage of 15% (SGF60) and 23% (SGF50) this should be doable without any excessive loss in lightweighting potential.

![Image of breaking stress](image)

**Fig. 5: Breaking stresses of PP-SGF50, PP-SGF60 and PA6-GF60**

4. Reinforcement of the foot plate of the TGL/M steel bumper
In the case of the small steel bumper the reinforcement of the foot plate was changed from PA6-GF50 to PP-SGF50. The reinforcement, which is to be seen on the right of Figure 6, carries the PET/PC foot plate. The plate has been given anti-slip pimples to ensure the safety of the driver when he climbs up. In the two cross-sections at the bottom of Figure 6 it can be seen how the reinforcement is incorporated into the lower flange of the steel bumper. The changeover was successfully completed. There were no problems handling the tread load of 6 kN.
5. Headlight holder - TGS/X steel bumper
This steel bumper has been fitted among other things to our heavy-haulage tractor units, which can move up to 250 tonnes gross combination weight.
The headlight holder, which accommodates both the main headlight and the light strip, was made of PBT/PET-GF45 until PP-SGF50 replaced it. Both test runs - operating strength and the environmental qualification - were passed with flying colors.

The light strip is a special item of equipment and includes fog lights, an additional high beam light and the cornering light. Since this is a relevant mass for vibration testing, it is also generally included on the test rigs.

6. Headlight holder - TGS/X plastic bumper

Here too the holders of the main headlight and of the light strip were changed over to PP. The headlight holder is screwed onto the frame front-end in the X direction and is additionally supported in the Z direction via the front underride protector (Figure 8).

Since there was no play in the connection between the side panels and the holder which could have enlarged during the course of testing, no anomalies arose in the dynamic vibration test or the alternating climate test. Production start for these holders in the beginning of 2017.

Fig. 8: Headlight holder - TGS/X plastic bumper
7. Summary and outlook

Our examples have shown that the HP-PPs have become a serious competitor to the glass-fiber-reinforced PA6 grades, and have the edge in the most important respects: CO₂, weight and cost. PA6 will find it becoming very difficult to assert itself.

Bibliography


