## Flame Retardance of Plastic Fibers

# Intrinsically Flame-Retardant Polyamide

**Polyamide fibers need to be sufficiently flame-retardant for the use in textile applications. Flame-retardants containing halogens and coating fibers with those is a common practice, although it has some severe disadvantages. Inherently flame-retardant polymers, which are processed along with polyamide to form blends and subsequently spun into fibers, provide an attractive alternative.**

With an annual production volume of approximately 5.4 million t and a share of 5 % of the global fiber market, polyamide (PA) fibers form the second largest group of synthetic fibers [1]. Polyamide fibers' applications range from home textiles and toothbrushes to airbags. A significant disadvantage of polyamide its low flame-retardant property. This disadvantage does not allow the use of polyamides in many applications without additional flame-retardants (FRs) [2].

FRs can protect the polymer with various mechanisms. One mechanism is the inhibition of the formation of reactive radicals that occur in the burning process of plastic. Other FRs forms develop into a protective layer on the polymer's surface to prevent oxygen from reaching the polymer or cooling the material by evaporating released water [3].

FRs containing halogens such as decabromodiphenyl ether (decaBDE) were predominantly used in the past. Due to their potential environmentally harmful and toxic properties, the use of halogen-based FRs is controversial. Additionally, decaBDE and many other halogen-free FRs are embedded in the polymer matrix as an insoluble filler material. This approach, in turn, negatively impacts the fibers' mechanical properties and leads to more frequent breakage of the filaments and reduced spinneret operating times during the manufacturing process [2, 4].

One approach to prevent this issue is coating the surfaces of textile structures with FRs [2]. This approach, however, has an economic disadvantage due to the added costs of the additional production step. Furthermore, coatings are often only active for a limited amount of time, and washing the textiles leads to a removal of the coating. The loss of flame-retarding properties is not the only adverse effect, as the halogen-based FRs could enter the environment with wastewater [5].

In recent years there have been several endeavors to develop FRs, that can be molten along with PA6 or PA66 and therefore embedded into polymer matrices. Currently, no products on the market are suited for different polymers, in particular pure PA6 and PA66. The Fraunhofer Institute for Structural Durability and System Reliability (LBF), Darmstadt, Germany, in cooperation with the Institut für Textiltechnik of RWTH Aachen University (ITA), Aachen, Germany, developed two novel phosphorous-based polymers that can be used as FRs and can be embedded into the fiber-matrix. By using these polymers, an additional step of coating textiles would be eliminated, and the production of intrinsically

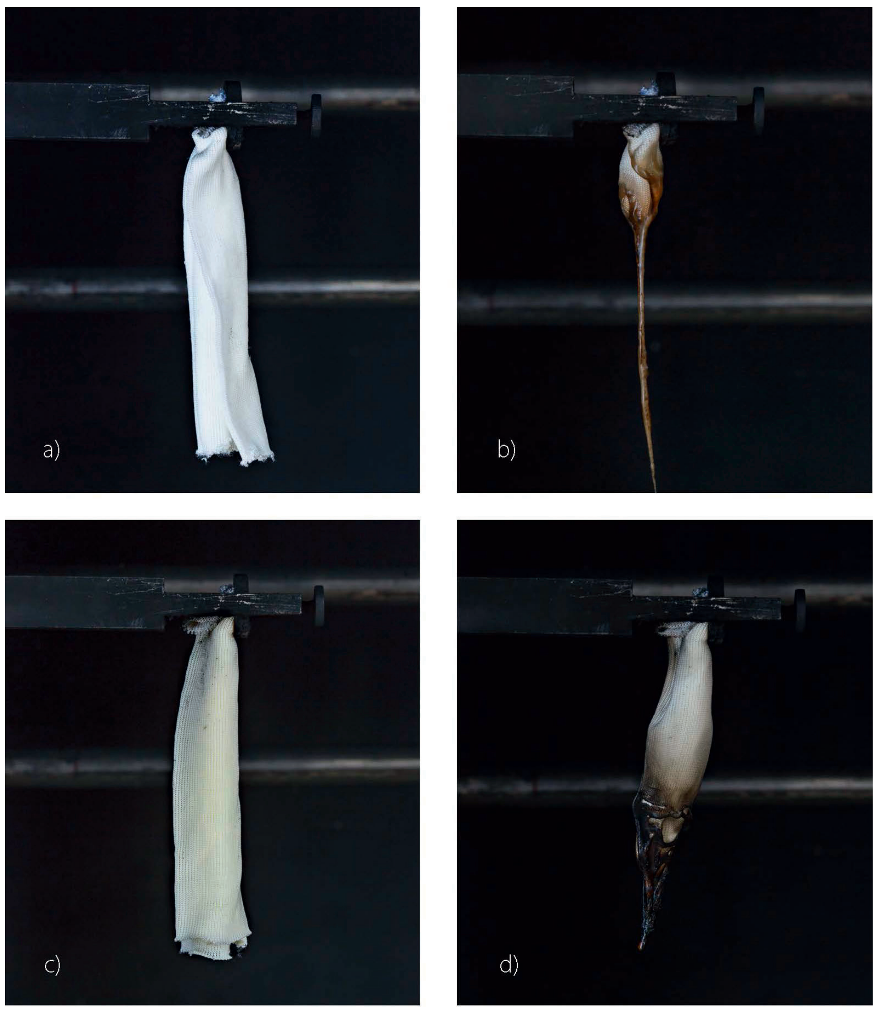


**Fig. 1.** Knitted fabrics made of untreated PA66 before a) and b) after the burning test, as well as a knitted fabric made of intrinsically flame-retardant PA66 before c) and d) after the burning test.
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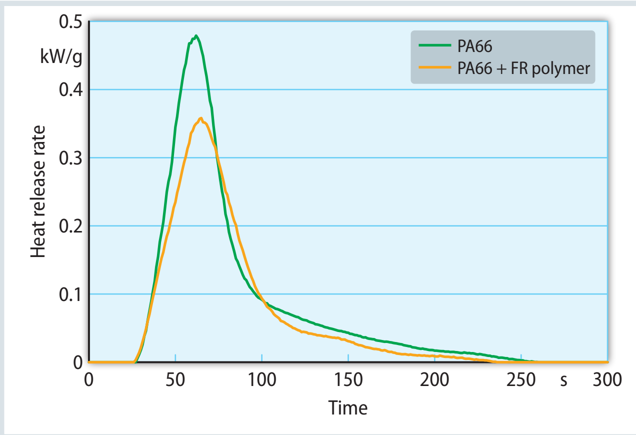


**Fig. 2.** Heat release rates of five-layer knitted fabrics made of PA66 and PA66 protected with polymeric FR: the reduced heat release is a reliable indicator of the FR's flame retardancy.

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flame-retardant fibers without a loss in mechanical properties is made possible.

These novel polymers are based on phosphorous derivates which exist in thermoplastic polymers as substituents. The FRs' melt spinning properties can be adjusted purposefully for the used polyamides through a variation of structural parameters such as the molar mass. The LBF-developed FRs were compounded along with PA66 at the ITA using a twin-screw extruder. The resulting polymer blends contained 10 wt. % of polymeric phosphorous FR. Subsequently, these blends were melt-spun into multifilament yarns and later processed into knitted fabrics on a circular knitting machine.

Particular FRs disrupt the polymer chains' orientation during the stretching of the fibers. However, the novel FRs developed by the LBF exist in the polyamide fibers as a polymeric blend component. During the stretching process, the polymer chains of the polyamide and the FR are oriented in the stretching-direction, which is pivotal for high mechanical strength [2, 6]. The mechanical properties of the produced fibers made of the blended polymer are comparable with those spun at the same spinning parameters with pure PA66. The high elongation at break of the yarns developed on a pilot scale indicates that a significant increase in strength can be expected from multi-stage post-drawing on an industrial scale melt spinning line. With further process optimization, there is a high probability of these fibers being appropriate for technical applications.

## *Reduced Incline to Produce Droplets*

The flame-retardant properties were analyzed with injection molded test rods made of pure PA66 and the compounded polymer based on UL94-V. As expected, the pure PA66 showed a strong tendency to produce flaming droplets, preventing the flames from spreading across the test rod. In turn, this property results in the undesired promotion of fire to the surroundings; therefore, it should be avoided. The compounded material showed a significantly reduced incline to produce droplets, in addition to creating a carbon layer that protected the rod from further ignition.

## *Flame-Retardance Demonstrated Successfully*

However, the results from these tests do not allow precise predictions about the burning behavior of textiles, as their surface area is significantly larger in comparison. For this reason, knitted surfaces made of pure PA66 and the compounded PA66 polymer were also analyzed. Both knits were tested based on UL94-V. The knit made of pure PA66 showed similar drop production to the testing rod. In comparison the entire sample burnt down completely. The knit made of the compound also shows an apparent reduction in droplet production compared to the pure PA66 knit. Furthermore, the knit also developed a carbon surface layer that prevented further ignition (**Fig. 1**).

Additional tests using a cone calorimeter show a reduced peak heat release rate (pHRR) for the compounded knit compared to the pure polymer (**Fig. 2**). Based on these results, a flame-retardant effect of the polymeric FR was shown. In particular, the flame-retardant effect was achieved while maintaining the textile properties. The next step will be to investigate the upscaling of the FRs synthesis and process optimization concerning high-strength industrial yarns. With an analysis of the market potential, the industrial realization of intrinsically flame-retardant PA should be made possible. The project is scheduled to start in 2023. ■

## Info

### Text

**Felix Krooss** has been working on developing polymer fibers with functional additives at the ITA since February 2020, while evaluating the melt spinning process with simulations and experiments;
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