SYNERGISTS FOR HEXAPHENOXYCYCLOTRIPHOSPHAZENE IN CAST PA6

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Introduction
Carbon fiber reinforced (CFR) anionic polyamide 6 (APA6) is a light and at the same time very strong material. Therefore CFR APA6 components are of interest as lightweight construction materials e.g. for aircraft manufacturing. Like many other organic polymers APA6 is flammable and thus it is mandatory to protect the polymer matrix by adding flame retardants (FRs). However, an suitable process for production of CFR APA6 materials such as thermoplastic resin transfer molding (T-RTM) process is highly sensitive to presence of polymer additives such as FRs. E.g. commonly used FRs interrupt the anionic ring opening reaction of ε-caprolactam to form PA6 or are filtered out by the fiber fleece. With hexaphenoxycyclotriphosphazene (HPCTP) we discovered an incorporated FR for CFR APA6.

Results
FRs TESTED IN LAB SCALE
FR requirements for CFR APA6 produced via T-RTM:
• Solubility in molten ε-Caprolactam
• No interruption of the anionic polymerization process

FR-TESTS
CFR APA6 with 15 wt.% HPCTP pass FAR and UL94 (V-0) test and shows highest LOI value.

Preparation
Only the HPCTP-FR Rabitile FP110 (Nordmann, Russmann) is applicable in T-RTM process for CFR APA6 with higher loading (see tested FRs).

T-RTM process
ε-Caprolactam
Catalyst FR
Heat
Mixing (1:1) T: 110 °C
Polymerization
T: 150 °C t: 360 s
p: normal
CFR: unidirectional

Plate (650x480x2 mm³; CFR: 64 wt.%, 53 vol.%)

The Heat Release Rate (HRR) decreases with increasing HPCTP load. Without HPCTP, CFR APA6 shows afterglow. Incorporation of HPCTP eliminates afterglow and promotes char formation.

Synergism
For future researches the influence of six additional additives in lab scale experiments was studied. Five of the examined compounds exhibited distinct synergistic effects with HPCTP in APA6 matrix. Although Trimethoxytriazine showed no synergy, it significantly improved flame resistance of APA6 as a stand-alone additive.

TGA OF FIBER-FREE APA6
HPCTP promotes in oxygen rich atmosphere (syn. air) the formation of thermally stable char. In an inert atmosphere (Nitrogen) no char formation is observed.

Conclusion
According to TGA and cone calorimetry, char formation is the essential FR mechanism of HPCTP in CFR APA6. Incorporation of only 15 wt.% HPCTP prevents afterglow (cone calorimetry) and allows the material to pass FAR and UL94 (V-0) tests. Following mechanical properties were obtained for CFR APA6 with 15 wt.% HPCTP (0° orientation).

Crystalinity: 40 %, Impact resistant: 96 kJ/m²
E-mod.: 116 GPa (flex.) 103 GPa (compr.) 134 GPa (Young) Strength: 1228 MPa (flex.) 483 MPa (compr.) 1471 MPa (tens.)