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Combined effect of decabromodiphenyl ethane and zinc borate on the flammability of high-impact polystyrene

João V.P. Zarth[1]; Amanda Cunha[1]; Gustavo L.Colpani[2]; Josiane M.M de Mello[2]; Luciano L. Silva[2]; Vanderlei A. Lima[1]; Jair Júnior[3]; Juliana R. Kloss[1]; Márcio A. Fiori[1].
[1] Federal University of Technology – Paraná (UTFPR); [2] Community University of the Chapecó Region (Unochapecó); [3] University of Western Santa Catarina (Unoesc).

Introduction

High-impact polystyrene (HIPS) is widely used because of its good processability and higher impact resistance than conventional polystyrene. However, its high flammability limits its use in applications with stricter fire-safety requirements (SUN et al., 2022). In this context, decabromodiphenyl ethane (DBDPE), a brominated flame retardant acting predominantly in the gas phase (LONG et al., 2024), and zinc borate (ZB), an inorganic additive acting in the condensed phase (SCHUBERT, 2019), form a promising combination. Although both additives are used individually, information on their combined effects in HIPS is still limited.

Objectives

To develop and characterize high-impact polystyrene formulations containing decabromodiphenyl ethane and zinc borate, evaluating the influence of additive contents on flammability and on the thermal, mechanical and morphological properties of the material. The study also seeks to investigate possible interaction effects between DBDPE and ZB, to correlate composition, processing and performance, and to identify conditions that provide the best balance among fire behavior, thermal stability, processability and mechanical integrity.

Methodology

HIPS formulations containing different contents of DBDPE and zinc borate (ZB) were prepared according to a 2^2 full factorial design with three center-point replicates and additional control formulations. The blends were first processed in a single-screw extruder (L/D = 28; D = 14 mm) with four heating zones at 170, 190, 190 and 196 °C. The extruded samples were then evaluated by a vertical burning test based on UL 94, considering burning behavior, dripping, cotton ignition and apparent smoke volume, which was assessed visually. The formulations with the best preliminary performance were reprocessed in a co-rotating twin-screw extruder (NZ Philpolymer SJSL-20; L/D = 32; D = 25 mm; 81 rpm) with eight heating zones at 175, 183, 187, 190, 195, 199, 200 and 200 °C, followed by pelletizing. Specimens were then injection molded in a 60-ton ROMI machine according to ASTM D638. The formulations will also be characterized by FTIR, TGA/DTG, DSC and SEM to relate composition, processing and performance.

Results and Discussion

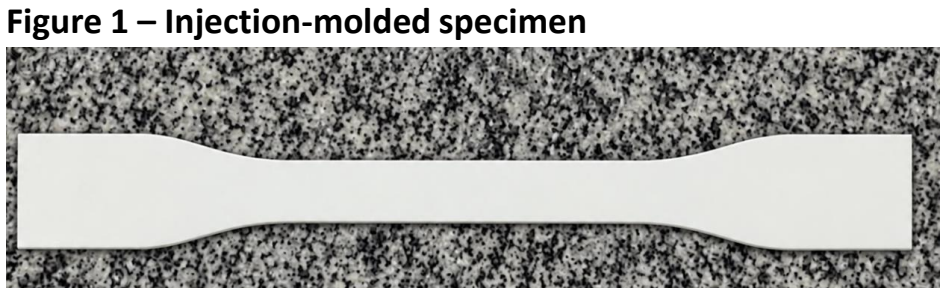
Preliminary results (Table 1) showed improved fire behavior with the addition of DBDPE, especially in formulations containing 20 phr of the additive. Formulations 2, 4 and 6 achieved a rating equivalent to V-0 in both test stages, whereas neat HIPS and ZB alone performed worse. At 18 phr DBDPE, adding 10 phr ZB improved the rating in both stages, from V-2 and V-1 (Exp. 12) to V-0/V-1 and V-0 (Exp. 11), suggesting a contribution of ZB near the efficiency threshold of DBDPE. The flame retardants also visibly reduced the apparent smoke volume, which was rated high for neat HIPS and mostly low for DBDPE-containing formulations. In tensile tests, the mean maximum stress ranged from 23.86 to 28.57 MPa, indicating that the additive composition also affects the mechanical response of the material. Overall, the results suggest that both the content and the combination of DBDPE and ZB play an important role in the overall performance of the formulations.

Table 1 – Results for the HIPS/DBDPE/ZB formulations

Exp.	DBDPE (phr)	ZB (phr)	1st stage	Smoke (1st)	2nd stage	Smoke (2nd)	Mean max. stress (MPa)
1	0	0	V-2	High	—	—	—
2	20	0	V-0	Low	V-0	Low	27.35 ± 0.73
3	0	12	V-2	Moderate	—	—	—
4	20	12	V-0	Low	V-0	Low	27.57 ± 0.31
5	10	12	V-2	Low	—	—	—
6	20	4	V-0	Low	V-0	Low	23.86 ± 0.40
7	10	4	V-2	Moderate	—	—	—
8	15	8	V-0/V-1	Low	—	—	—
9	15	8	V-0/V-1	Low	V-2	Low	28.27 ± 0.35
10	15	8	V-0/V-1	Low	—	—	—
11	18	10	V-0/V-1	Low	V-0	Low	28.57 ± 0.90
12	18	0	V-2	Low	V-1	Low	28.02 ± 0.57

Source: The authors (2026).

Figure 1 – Injection-molded specimen



Source: The authors (2026).

Conclusions

The preliminary results show that DBDPE improves the fire behavior of HIPS and reduces the apparent smoke volume. ZB alone did not perform equivalently, but its combination with DBDPE gave promising results at certain contents, particularly 18 phr DBDPE with 10 phr ZB. Formulations containing 20 phr DBDPE, with or without ZB, gave the best results in the tests performed. Whether DBDPE and ZB act synergistically remains to be confirmed by jointly considering the flammability, thermal, mechanical and morphological results.

References and Acknowledgments

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