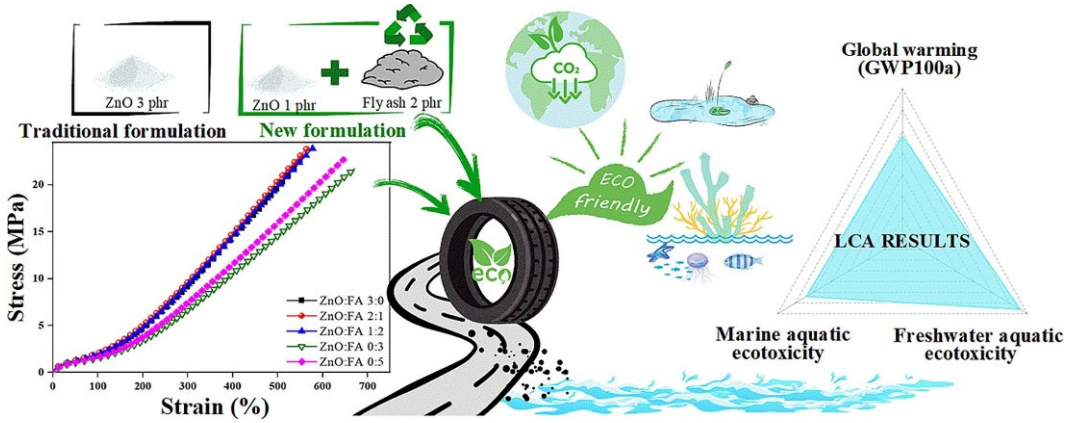
Sustainable fly ash waste in tire tread rubber: physical properties analysis and environmental impact evaluation

Hassarutai Yangthong[1], Papawarin Udomsin[1], Siriwan Jansinak[1], Supitta Suethao[1,2], Kheng Lim Goh[3,4], Wirasak Smitthipong[1,2]

e-mail: fsciwssm@ku.ac.th

[1]*Specialized Center of Rubber and Polymer Materials in Agriculture and Industry (RPM), Department of Materials Science, Faculty of Science, Kasetsart University, Bangkok 10900, Thailand*
[2]*Hub of Talents in Natural Rubber, National Research Council of Thailand (NRCT), Bangkok 10900, Thailand*
[3]*Newcastle University, Faculty of Science, Agriculture and Engineering, Newcastle upon Tyne, UK*
[4]*Newcastle University in Singapore, Singapore*

This study investigates the utilization of fly ash (FA), a byproduct, to partially substitute zinc oxide (ZnO) as an activator in tire tread manufacturing. Minimizing ZnO lowers its environmental hazards, including the effects of ZnO leaching into aquatic environments during the tire's lifecycle. The FA was modified by including a rubber composite with and without ZnO, utilizing ZnO-to-FA ratios of 3:0 (control), 2:1, 1:2, 0:3, or 0:5 parts per hundred of rubber (phr). The findings indicate that crosslinking of the rubber composite transpired with FA, even in the absence of ZnO. Significantly, sample formulations with ZnO-to-FA ratios of 2:1 and 1:2 phr exhibited Δ torque values comparable to the control (3:0), facilitating ZnO reductions of 33.7% and 67.0%, respectively [1]. The efficacy is presumably attributable to metal oxides in FA, including CaO, MgO, Al_2O_3, and Fe_2O_3, which facilitate the vulcanization process. Furthermore, the tensile strength and modulus exhibited no variation. Elemental analysis revealed that a ZnO-to-FA ratio of 1:2 decreased zinc release by 63.0% relative to the control formulation. A comprehensive life cycle study indicated that substituting ZnO with FA in vulcanized rubber formulations diminishes environmental impacts, with the minimal effects noted at the 0:3 ZnO:FA ratio; nevertheless, an increased FA concentration may elevate consequences. The utilization of FA as a partial substitute for ZnO in tire tread processing demonstrates potential for mitigating environmental impact in tire production by diminishing zinc release, minimizing ecotoxicity, and fostering waste reduction via the recycling of fly ash.



References 1) H. Yangthong, et al., *Waste Management* 200, 114737 (2025).