

Supporting Information

Effects of Zinc-Free Processing Aids in Silica-reinforced Tread Compound for Green Tire

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Table S1. Characteristics of the ZFAs.

Sample	ZCAs	ZFAs
Acid Value (mg KOH/ g)	142.0	11.9
I ₂ (mg I ₂ / g)	38.7	0.38
Melting point (°C)	102.5	57.1
Ash content (%)	13.2	0.01
Zinc content (%)	8.34	0.0
Heating loss (%)	0.14	0.21

Table S2. Formation of rubber composites with varying loading fraction of processing aids.

Unit: phr

Materials	Control	ZCAs 1	ZCAs 2	ZCAs 4	ZFAs 1	ZFAs 2	ZFAs 4	Injection Material	Injection Time
SBR	80	80	80	80	80	80	80	SBR Silica Master Batch Chemical Drop	0 30 100 180 300
Silica	20	20	20	20	20	20	20		
Stearic Acid	1	1	1	1	1	1	1		
Coupling agent	2	2	2	2	2	2	2		
ZCAs	-	1	2	4	-	-	-		
ZFAs	-	-	-	-	1	2	4		
ZnO	2	2	2	2	2	2	2		
Sulfur	1.75	1.75	1.75	1.75	1.75	1.75	1.75		
TBBS	1	1	1	1	1	1	1		

Master batch: Silica with processing aids/SBR Latex

Chemical: Steric acid, sulfur, TBBS

Table S3. Formation of rubber composites with varying loading fraction of silica.

Unit: phr

Materials	Control	Silica-ZCAs 2	Silica-ZCAs 4	Silica-ZCAs 6	Silica-ZFAs 2	Silica-ZFAs 4	Silica-ZFAs 6	Injection Material	
SBR	80	80	80	80	80	80	80	SBR Silica Master Batch Chemical Drop	0 30 100 180 300
Silica	20	20	40	60	20	40	60		
Coupling agent	2	2	2	2	2	2	2		
Stearic Acid	1	1	1	1	1	1	1		
ZCAs	-	2	2	2	-	-	-		
ZFAs	-	-	-	-	2	2	2		
ZnO	2	2	2	2	2	2	2		
Sulfur	1.75	1.75	1.75	1.75	1.75	1.75	1.75		
TBBS	1	1	1	1	1	1	1		

Master batch: Silica with processing aids/SBR Latex

Chemical: Steric acid, sulfur, TBBS

Table S4. The parameter values of SBR composites with varying loading fraction of processing aids

Materials	ω	ΔC_p	ΔC_{pn}	χ_{im}	Tan δ	W	C
ZCAs 2 phr	0	0.465	0.490	2	1.672	0.840	0.01
ZCAs 4 phr	5	0.460	0.484	3.2	1.516	0.826	0.016
ZFAs 2 phr	5	0.450	0.474	5.2	1.386	0.812	0.033
ZFAs 4 phr	5	0.443	0.466	6.8	1.275	0.800	0.048

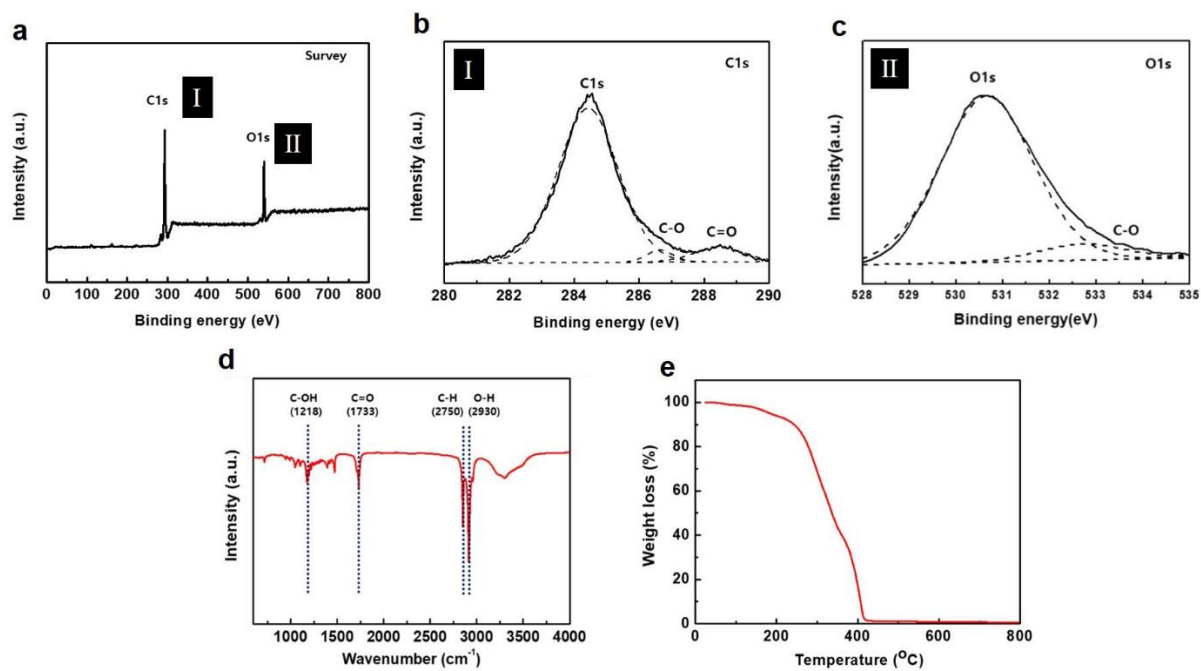


Figure S1. Characterization of as-prepared ZFAs.

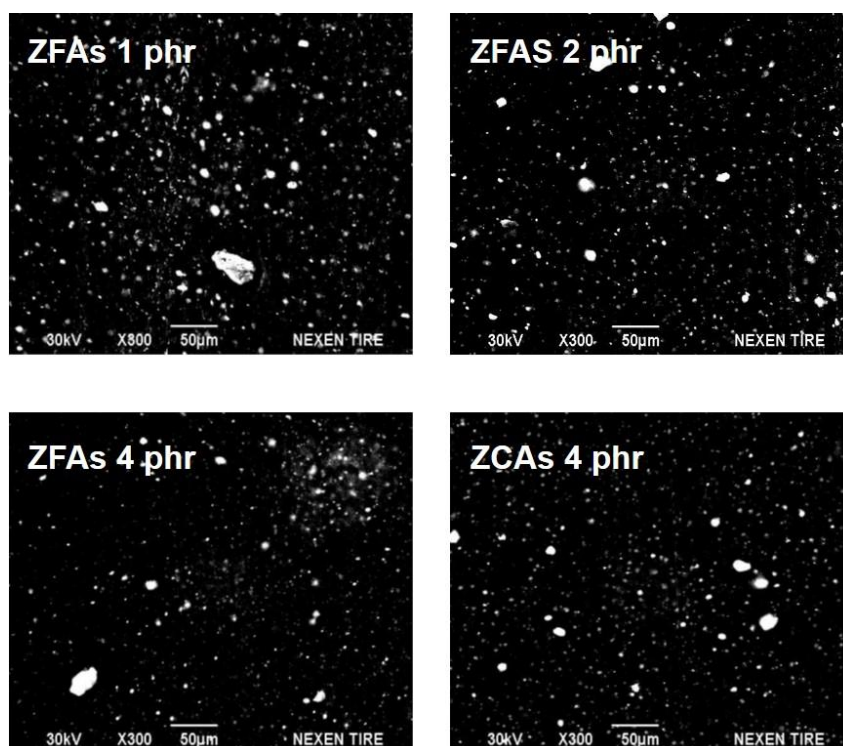


Figure S2. SEM images of rubber composites with varying loading fraction of ZFAs and ZCAs.

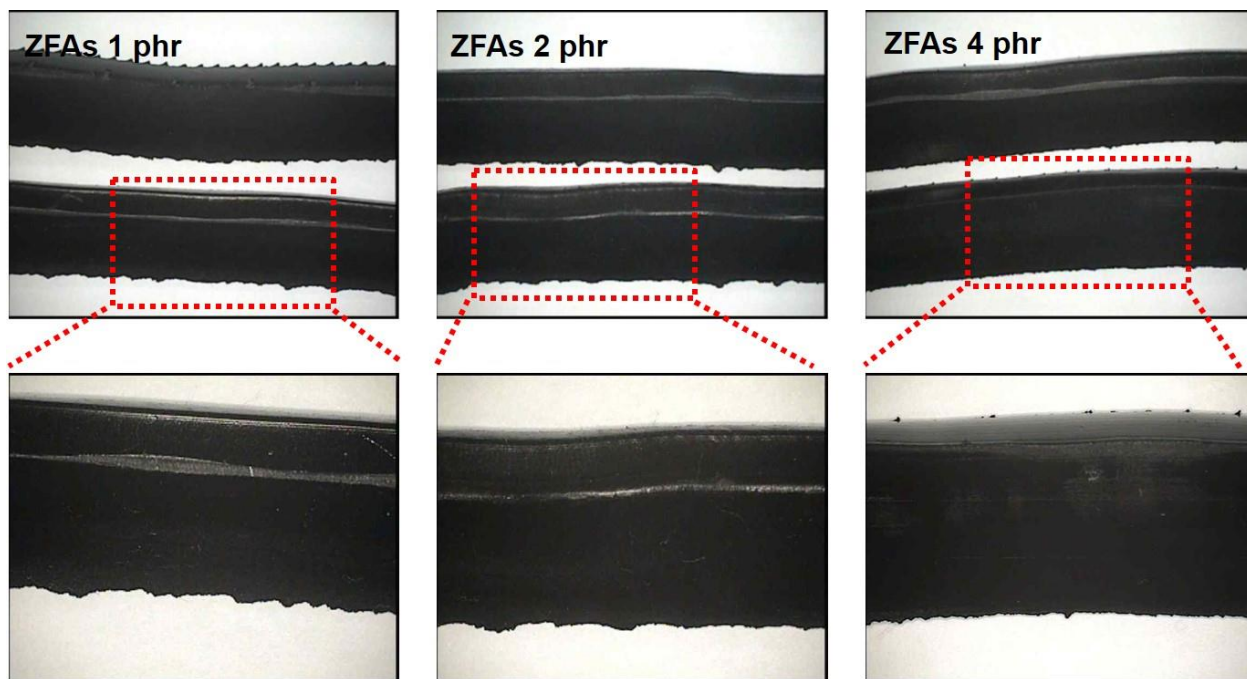


Figure S3. Gravel Die Extrusion images of rubber composites with varying loading fraction of ZFAs.

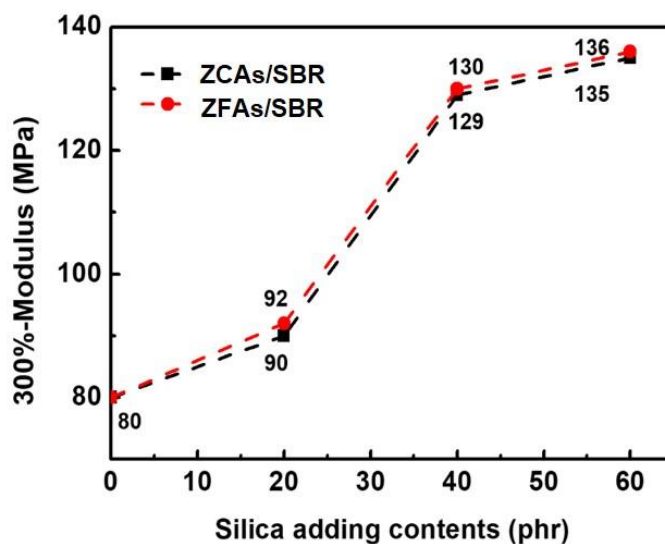


Figure S4. Modulus of rubber composites with ZCAs and ZFAs with varying loading fraction of silica.

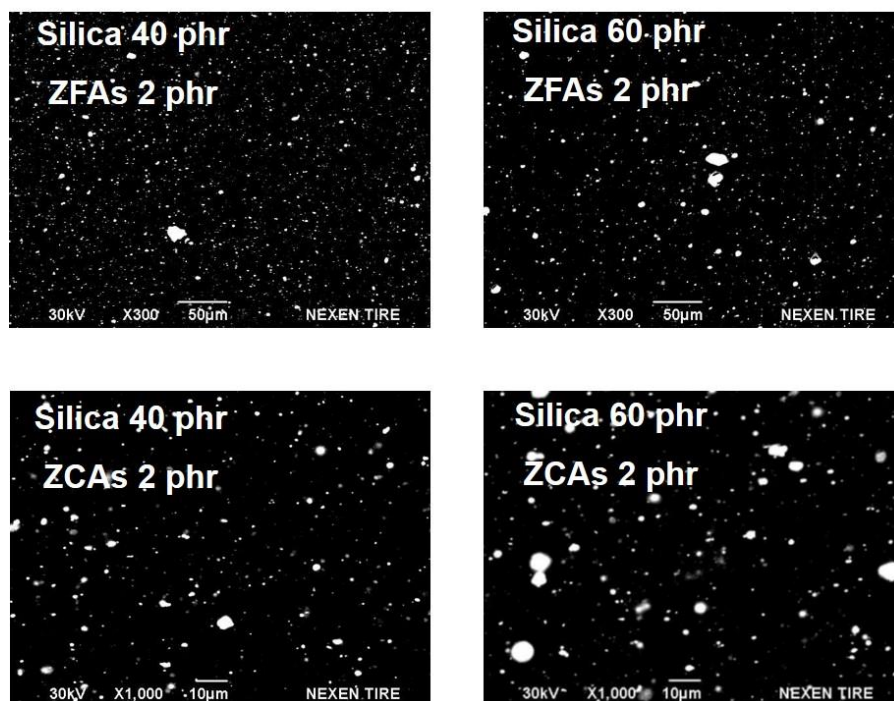


Figure S5. SEM images of rubber composites with ZCAs and ZFAs with varying loading fraction of silica.

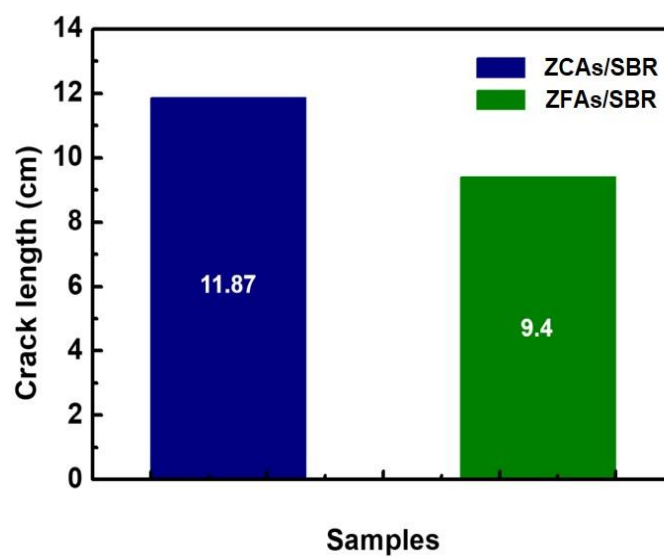


Figure S6. Fatigue properties of rubber composites with ZCAs and ZFAs.