Fire Safety Performance of Polymer Composites

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The growth of the use of polymer composite materials has been a phenomenon since 1960, with diverse applications in spacecraft, aircraft, boats, ship, automobiles, civil infrastructure, sporting goods, and consumer products. In addition, the use of composites will continue to grow in the coming years with emerging end-use such as large bridge structures, engine machinery, offshore platforms, computer hardware, and biomedicals devices. However, a critical challenge facing the growing use of polymer composites is their high combustibility.

composites | next generation burner (NexGen) | Thermogravimetric analysis (TGA) | Cone calorimeter

1. Introduction

Over the years, researchers have made several attempts to come up with solutions to the problems associated with the use of polymer composite materials. The most successful attempt reported in the literature is the strategy of incorporating a novel chemical substance known as a fire retardant into the polymer matrix to suppress fire (heat release and temperature) and minimise the gas emission species that could be a source of toxicity via the mechanism of the solid phase and gaseous phase phenomena [1][2][3][4].

Regardless of the scale used, it is vital to ensure that the fire reaction tests are carried out in conditions that precisely reproduce the type of fire in which the composite materials will be subjected.

2. Fire Safety Performance and Smoke (Toxic Gas) Emission of Composites

At high temperatures, the residue does not emit any dangerous gas and acts as an effective insulation layer on the sample's surface, protecting the underlying material from fire.

Researchers have performed quite a number of studies on the fire behaviour and the protection of polymer composite materials used especially as vital components in the transport sectors and building element under fire condition [5]. The bench-scale platform of the medium scale has provided significant fire testing parameters that indicate the fire reaction and fire resistance of the materials assessed (as shown in **Table 1** , **Table 2** , **Table 3** and **Table 4**) e.g., a cone calorimeter test (CCT), limiting oxygen index (LOI), and underwriter's laboratories (UL-94).

Thus, the results have been a useful guide in the evaluation of the fire hazard risk and the smoke and toxic gases examination.

Table 1. The experimental working scales adopted to investigate the flammability and combustibility of composites [6].

Specimens (Codes)	pHRR (kW/m^2)	THR (MJ/m^2)	TTI (s)	pHHR/t_{ig} (kWm^2s^1)	Residual Mass (%)	TSP (m^2/kg)	TSR (m^2/m^2)	SEA (m^2/kg)	CO Yield (g/kg)	CO_2 Yield (kg/kg)	LOI	UL-94	Citations
A-10	361	67	31	16.2	-	20.9	-	762	0.128	-	25.4	HB	
B-10	429	60	54	8.1	-	20.4	-	838	0.199	-	25.0	HB	
AS-5	348	63	58	6.0	-	21.8	-	918	0.333	-	26.4	HB	
BS-5	335	59	60	5.6	-	19.1	-	756	0.053	-	27.7	HB	[7]
BS-0	433	66	60	8.2	-	17.7	-	505	0.074	-	28.0	HB	
B1S-5	306	55	60	5.1	-	18.9	-	728	0.268	-	28.8	HB	
B1S-10	416	63	59	5.8	-	16.7	-	614	0.279	-	29.0	HB	
Pure PLA	752	171.1	37	209	−3.66	40.8	-	-	0.037	-	21.5	NR	
MX0.5	920	170.4	32	209	−0.30	47.5	-	-	0.030	-	20.0	NR	
MX1.0	803	167.7	32	207	0.00	41.0	-	-	0.028	-	20.0	NR	
MX2.0	715	178.9	35	254	0.53	20.8	-	-	0.035	-	20.5	NR	[8]
F12.0	431	136.3	41	246	4.04	457.4	-	-	0.097	-	30.0	V-1	
F11.5MX0.5	263	144.5	39	389	5.86	178.1	-	-	0.062	-	33.0	V-0	
F11.0MX1.0	266	142.7	35	415	7.82	244.3	-	-	0.059	-	34.5	V-1	
F10.0MX2.0	410	149.6	30	252	6.36	282.0	-	-	0.072		28.0	V-1	
Pure WPC	347	191	26	-	16.4	-	-	-	-	-	-	-	
WPC + 3wt% FR	323	179	23	-	22.9	-	-	-	-	-	-	-	[9]
WPC +10wt% FR	311	175	22	-	25.2	-	-	-	-	-	-	-	

Calorimeter (irradiance, 50 kW/m^2), LOI and UL-94 results. TSP: total smoke production, TSR: total smoke release SEA: specific extinction area.

Table 2. Cone calorimeter (irradiance, 50 kW/m^2), LOI, and UL-94 results.

Specimens (Codes)	pHRR (kW/m^2)	THR (MJ/m^2)	TTI (s)	pHRR/t_{ig} (s)	Residual Mass (%)	TSP (m^2/kg)	TSR (m^2/m^2)	SEA (m^2/kg)	CO Yield (g/kg)	CO_2 Yield (kg/kg)	LOI	UL-94	Citations
AcF20 (2 mm)	285.7	19.6	30	-	35.5	-	-	-	0.04	1.68	-	-	
AcF40 (4 mm)	280.4	39.9	49	-	28.2	-	-	-	0.10	1.50	-	-	
AcF3 (3 plies)	161.3	4.5	9	-	26.1	-	-	-	0.51	1.29	-	-	
AcF5 (5 plies)	162.0	13.2	17	-	35.0	-	-	-	0.36	1.49	-	-	[10]
AcF7 (7 plies)	144.0	15.5	24	-	39.0	-	-	-	0.65	1.16	-	-	
AcF8 (8 plies)	169.4	11.1	27	-	28.9	-	-	-	0.21	1.19	-	-	
AcF9 (9 plies)	175.3	15.9	31	-	17.2	-	-	-	0.47	1.63	-	-	
Cotton	100	10.0	22	73	0.0	2.2	-	-		-	-	-	
Cotton4/alginat1	89	9.40	28	86	2.7	0.2	-	-		-	-	-	
Cotton5/alginat5	68	7.20	42	87	8.4	0.2	-	-		-	-	-	[11]
Cotton1/alginat4	46	9.70	71	97	10.4	1.9	-	-		-	-	-	
Alginate	49	3.50	103	123	23.9	0.9	-	-		-	-	-	
PP	1620	110	24	-	-	-	980	-	36.6	3.16	-	-	
PP/MWNT	931	102	17	-	-	-	1310	-	44.2	2.89	-	-	
PB	1420	111	35	-	-	-	1090	-	36.4	3.01	-	-	[12]
PB/MWNT	830	108	18	-	-	-	1545	-	40.5	2.90	-	-	
PE	1700	125	39	-	-	-	1075	-	30.3	3.36	-	-	
PE/MWNT	920	111	37	-	-	-	1315	-	35.1	3.14	-	-	

TSP: total smoke production, TSR: total smoke release, SEA: specific extinction area.

Table 3. Cone calorimeter (irradiance, 35 kW/m^2), LOI, and UL-94 results.

Specimens (Codes)	pHRR (kW/m^2)	THR (MJ/m^2)	TTI (s)	pHRR/t_{ig} (s)	Residual Mass (%)	TSP (m^2/k)	TSR (m^2/m^2)	SEA (m^2/k)	CO Yield (kg/kg)	CO_2 Yield (kg/kg)	LOI	UL94	Citations
GRPBT	417	53.6	49	-	35.5	354	-	520	0.052	1.64	-	-	
GRPBT/AHP	121	40.5	30	-	28.2	222	-	388	0.144	1.15	-	-	[1]
GRPBT/LHP	105	43.7	36	-	26.1	320	-	475	0.128	1.52	-	-	
GRPBT/CHP	101	42.8	38	-	35.0	198	-	249	0.122	1.42	-	-	
PPO	467	110	97	-	26	-	1303	-	0.14	-	29	V-0	
PPO-30AlPi	130	102	125	-	52	-	1994	-	0.18	-	43	V-0	
TPU	613	111	84	-	6	-	1229	-	0.04	-	24	HB	
TPU-30AlPi	447	108	70	-	13	-	3029	-	0.16	-	24	V-0	[13]
PP	480	125	66	-	2	-	1305	-	0.04	-	17	HB	
PP-30AlPi	524	111	73	-	10	-	2310	-	0.16	-	27	HB	
EP	1063	76.1	59	130	11.9	71.4	-	-	-	-	26.2	NR	
EP/10APP	754	42.8	63	105	45.7	30.6	-	-	-	-	30.2	NR	[14]
EP/7.5APP/2.5BPOPA	576	42.6	61	100	47.2	25.9	-	-	-	-	33.1	V-0	
EP	1063	114	76	-	3	-	3626	829	-	-		HB	
20HS	729	106	63	-	3	-	2768	636	-	-		HB	
20LHP	166	37	59	-	50	-	1016	459	-	-		HB	[15]
15HS/5LHP	577	80	57	-	13	-	2441	624	-	-		HB	
5HS/15LHP	169	35	59	-	54	-	899	435	-	-		HB	

TSP: total smoke production, TSR: total smoke release SEA: specific extinction area.

Table 4. CCT (irradiance, 50kW/m^2), LOI, and UL-94 results.

Samples	pHRR (kW/m^2)	THR (MJ/m^2)	TTI (s)	pHRR/t_{ig} (s)	Residual Mass (%)	TSP (m^2/kg)	TSR (m^2/m^2)	SEA (m^2/kg)	CO Yield (g/kg)	CO_2 Yield (kg/g)	LOI	UL-94	Citations
GF_{30}-PBT	345	118	30	105	35.5	-	3987	-	-	-	20.0	NR	
GF_{30}-PBT10	136	82	49	65	28.2	-	3958	-	-	-	23.2	NR	
GF_{30}-PBT15	113	74	9	60	26.1	-	3548	-	-	-	27.0	V-0	[16]
GF_{30}-PBT20	107	75	17	60	35.0	-	2747	-	-	-	28.5	V-0	
GF_{30}-PBT25	105	71	24	60	39.0	-	2101	-	-	-	32.5	V-0	
Neat Furan	682	30.9	98	-	44.0	-	117	-	0.0203	1.37	-	-	
F/AS-40 amino	554	24.4	103	-	50.5	-	109	-	0.0249	1.42	-	-	
F/AS-40 isocy	556	30.7	104	-	50.9	-	108	-	0.0277	1.41	-	-	[17]
F/PT-40AS isocy	507	23.8	100	-	49.7	-	96	-	0.0241	1.30	-	-	
F/PT-40AS amino	569	26.9	95	-	50.2	-	92	-	0.0239	1.31	-	-	

TSP: total smoke production, TSR: total smoke release SEA: specific extinction area.

Furthermore, the remarkable decreased smoke and toxic gas release revealed by the alternating composite in the cause of the combustion process is extremely important to reduce the harm to people in case of fires.

In order to improve the fire behaviour of the polyester resin, different phosphate fire retardants, ammonium polyphosphate (APP), silane-coated ammonium polyphosphate (S-APP), and melamine pyrophosphate (MPP) were dispersed within the resin.

3. Conclusions

This review has successfully explored the application of the various classes of the thermal and combustion state-of-the-art facilities deployed for the evaluation of the flammability and thermal stability of polymer composites.

Summarily, the small-scale facilities (such as TGA, MCC, etc.) provide detailed understanding and mastery of the thermal reaction properties of the composites. While with the medium scale, extended fire reaction parameters, which are the key indicators of the fire safety performance such as the pHRR, THR, TTI, TSP, CO/CO 2, etc. can be determined.

Furthermore, novel polymer composite materials, particularly from bio-sources (because of their environmental friendliness, economic concerns, and acceptable fire safety performance) could be designed and tested as a potential substitute for synthetic composites in the transportation sector.

In finality, this paper seeks to provide a new perspective that will encourage more research efforts in this scientific domain, especially at the large scale.

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