Electronic Supplementary Information (ESI)

An Emerging Air Pollution Mobile Source: Outdoor Plastic Liner Manufacturing Sites Discharge VOCs into Urban and Rural Areas

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S1. INTRODUCTION

Table S1 List of CIPP associated air contamination incidents found by authors not included in the 59 incidents reported by Teimouri et al. (2017) and 45 incidents reported by Ra et al. (2019) in their Supplementary Information files.

Incident Location (Year)	Styrene	Description of events from reference
Philadelphia, PA (2020) [1]	nr	PERSONAL COMMUNICATION: A resident found her house filled with CIPP fumes which entered to the building through the basement. She left the house and contacted the water department and contractors. A water department inspector came to her house but only prepared a report. The resident was a cancer survivor with neuropathy, and that became worse after the incident.
Harrisburg, PA (2020) [2,3]	nr	PERSONAL COMMUNICATION: A resident noticed a strong glue-like smell in his basement coming from an underground work in the neighborhood. The resident asked the workers the cause of such smell and they assured him that the smell would vanish and not be as strong as it cures. The resident was concerned because: 1) the incident happened during the winter and they expect residents to open windows to ventilate; 2) it affected those who may be elderly, working remotely or children who may be home schooled or in cyber school; 3) nobody in the City of Harrisburg Codes was too concerned. They also said that there was no oversight from the City government of the process or possible health, safety, welfare of residents; 4) With the population being 25% under the age of 18, any type of chemicals can adversely affect brain development up until 25 years of age; 5) With older houses, many times there are floor drains that may not have a functioning trap as in the case of our house. However, the Capital Region Water released a notice in which they claimed that “the smell released in sewer rehabilitation process is in such small quantities that it does not pose a significant risk to human health, the environment, or the workers who are working on our behalf. It exists briefly in the environment and is destroyed rapidly in the air, disappearing quickly.”
Chicago, IL (2020)[4]	nr	MEDIA REPORT: Sewer pipe repair construction caused a very strong chemical smell adversely impacted business at a bakery in Chicago.
Decatur, IL (2020)[5]	nr	Cancer Care Center of Decatur was evacuated due to an odor caused by city sewer projects. Decatur Fire Department responded to the incident

Incident Location (Year)	Styrene	Description of events from reference
		but did not find anything unsafe.
Seneca Falls, NY (2019)[6]	nr	MEDIA REPORT: A teacher and several middle school students in a classroom became sick because of inhalation of odors caused by sewer pipe rehabilitation work at nearby area. Windows of the classroom were opened when the rehabilitation work was taking place. Nine students went home sick at the incident day. Eight students felt better and returned school the next day while one student still felt sick two days later. Styrene, as a volatile organic compound, was mixed with the resin to help it cure. An engineer for the project from Barton & Loguidice Engineers told the reporter that curing of the resin impregnated liner causes odors. He also mentioned that results of some studies showed that even though odors are a common occurrence in CIPP practices, styrene concentrations are less than exposure guidelines and do not lead to health risk. He said that individuals have different sensitivities towards styrene odors and can be inconvenient to those who are not used to working around it. After investigation it was concluded that a combination of weather conditions (i.e. breeze and air movement at the incident day) and opened windows resulted in increased odors from the CIPP process.
Festus, MO (2019)[7]	nr	MEDIA REPORT: Public Works director Matt Clemens announced that while fabric lining in sewer lines was conducting in Festus, residents may notice a strange odor. He said that this process has been conducted every other year on a rotating basis and nothing harmful exists in this procedure.
Regina, CAN (2019)[8]	nr	MEDIA REPORT: One of the residents found going outside impossible because of massive maintenance project being conducted nearby her house. The noise and fumes from the project have disrupted her daily life. Some residents noticed sewer gas smell after steaming the pipe. said some people have been put as a result of the project, but only Residents directly affected by the noise and fumes were put in hotels while contractor decided when a house should be evacuated.
Regina, CAN (2019)[9]	nr	PERSONAL COMMUNICATION: Explosion in a basement in sump pit occurred as a result of fume accumulation during sewer pipe lining. CIPP was installed a few months prior the incident. The pit was connected to sanitary sewer. During CIPP installation styrene residue settled in pit for

Incident Location (Year)	Styrene	Description of events from reference
		4 months and the spark was from the pump and ignited gas.
Herndon, VA (2019)[10]	nr	PERSONAL COMMUNICATION: Residents were concerned about a strong smell assumed to originate from chemical reaction to the epoxy in the sewer pipe. The chemical odor became worse in the past 30 minutes of incident report. It was advised that the odor would dissipate by the morning and was not harmful.
Pitcairn, PA (2019)[11]	nr	MEDIA REPORT: Three students and three teachers felt ill after breathing emissions from a sewer project near school. It caused nausea and watery eyes for students and staff. 280 students and staff were vacated from the school and students were sent home an hour later.
Rochelle, IL (2019)[12]	nr	MEDIA REPORT: Aldi evacuated the building and stayed closed for several hours as a result of smoke coming from restrooms. A strong odor was also noticed in the building and parking area. Sewer pipe rehabilitation work near the area was the reason for smoke and strong smell. Rochelle fire chief explained that they monitored the air nothing harmful, flammable or explosive was found.
Evanston, IL (2019)[13]	nr	MEDIA REPORT: City officials announced a sewer repair work will be conducted and advised nearby residents not to distress by unpleasant odors caused by heated styrene. The chemical has been commonly used in fiberglass industry and is not dangerous. They also asked the residents to pour a gallon of water into drains to avoid the odor in their home and repeat the process when the water evaporates.
Festus, MO (2019)[14]	nr	MEDIA REPORT: In March, Instituform was awarded $130,124 by Festus City Council to repair city sewer pipes by CIPP installations. There’s no need to worry about steam rising from Festus streets, Public Works Matt Clemens said.
Moncton, CAN (2019)[15]	nr	MEDIA REPORT: An unpleasant glue-like odor came from sewer lining activities and permeated homes in the city's north end. The city declared the smell isn’t a public-health risk. However, some residents developed headaches and felt nauseous. One resident rented an industrial fan to force the smell out of his building. A few of them smelt the odor on their cloths, furniture and even bottled water.

Incident Location (Year)	Styrene	Description of events from reference
Norwalk, CT (2019)[16-18]	nr	MEDIA REPORT: All students' after school activities were canceled due to an odor from an adjacent construction. The students left the building by local Fire Department personnel "out of an abundance of caution".
Pitcairn, PA (2019)[19]	nr	MEDIA REPORT: Students were sent home after several were sickened by an odor from a nearby sewer lining project. A 5th grade student was among the six people taken to the hospital after inhaling the odor.
Ontario, CAN (2019)[20]	nr	PERSONAL COMMUNICATION: A resident found their house saturated with a peculiar chemical smell came from sewer pipes working in the neighborhood. The odor got into the house through sewer pipes of toilets. The house was also filled with a high roaring sound that came from some violent action in the toilet bowls. The resident alerted the authorities. A group of inspectors/engineers arrived at the incident place and after investigation they ordered the residents leave the house as the gas concentrations were beyond an acceptable level. The residents stayed at hotel overnight until the house is properly ventilated. In the incident place, windows were opened, and a large number of fans were installed to ventilate. Project engineers claimed that this has never happened before and then modified to a chance of one in a million.
Warsaw, IN (2019)[21]	nr	PERSONAL COMMUNICATION: Several residents were concerned and complained about glue like odor in their homes as a result of sewer pipe lining conducted in their neighborhood. Wastewater Treatment Utility Plant responded to the residents by saying that the odor is not toxic and residents can avoid it by pouring water to their plumbing traps.
Deerfield beach, FL (2019)[22]	nr	MEDIA REPORT: Individual reported that emissions entered a single-family home during sanitary sewer CIPP installation in front of the house. When she arrived, she opened the door, smelled a glue-like odor in the house, and found 2 adults unconscious. The individual then called 911.
Jersey City, NJ (2019)[23]	nr	PERSONAL COMMUNICATION: The resident found the CIPP odor overwhelming and noticeable in his second floor apartment. The city never notified residents of this project.
Warrnambool, AU (2018)[24]	nr	MEDIA REPORT: Warrnambool residents were told that a strong plastic-like smell originating from an innovative sewer repair project and persisting in parts of the city was not toxic and disappeared very quickly.

nr = not reported in the reference

S2. MATERIALS AND METHODS

S2.1. Analytical standards for liquid-solid extraction samples

Different analytical standards were used to confirm and quantify some compounds identified by GC/MS. They include: butyl hydroxytoluene (BHT) (CAS# 128-37-0, Supelco), benzaldehyde (CAS# 100-52-7, Sigma-Aldrich), benzoic acid (CAS# 65-85-0, Supelco), 1-tetradecanol (CAS#112-72-1, Sigma-Aldrich), , chlorobenzene-d5 (CAS# 3114-55-4, Supelco), styrene oxide 97% (CAS# 96-09-3, Sigma-Aldrich), hydroquinone (CAS# 123-31-9, Sigma-Aldrich), 3-ethyl-1-methylbenzene (CAS# 620-14-4, Sigma-Aldrich), 2-ethylhexanoic acid (CAS# 149-57-5, Supelco), 2-propenylbenzene (CAS# 300-57-2, Sigma-Aldrich), *N*-propylbenzene (CAS# 103-65-1, Supelco), 1,3,5-trimethylbenzene (CAS# 108-67-8, Supelco), 1,2,4-trimethylbenzene (CAS# 95-63-6, Sigma-Aldrich) and styrene ≥99% that contained 4-tert-butylcatechol stabilizer (CAS# 100-42-5, Sigma-Aldrich).

Calibration curves were developed for methylene chloride extracts: styrene (R^2 = 0.991, 0.992) benzaldehyde (R^2 = 0.998), 1,3,5-trimethylbenzene (R^2 = 0.985, 0.998), 1,2,4-trimethylbenzene (R^2 = 0.991), benzoic acid (R^2 = 0.998), 1-tetradecanol (R^2 = 0.995), *N*-propylbenzene (R^2 = 0.999, 0.998), 2-propenylbenzene (R^2 = 1), styrene oxide (R^2 = 0.997), 3-ethyl-1-methylbenzene (R^2 = 0.999, 0.980), 2-ethylhexanoic acid (R^2 = 0.999, 0.961), hydroquinone (R^2 = 0.998) and BHT (R^2=0.995).

Calibration curves were also created for hexane extracts and were for: styrene (R^2= 0.996, 0.999), benzaldehyde (R^2 = 0.999, 0.998), 1,3,5-trimethylbenzene (R^2 = 0.999, 0.991, 0.980) , 1,2,4-trimethylbenzene (R^2 = 0.998, 0.997), benzoic acid (R^2 = 0.980, 0.950), 1-tetradecanol (R^2 = 0.982), *N*-propylbenzene (R^2 = 0.999, 0.997), 2-propenylbenzene ((R^2 = 0.999), styrene oxide (R^2 = 0.995), 3-ethyl-1-methylbenzene (R^2 = 0.994), 2-ethylhexanoic acid (R^2 = 0.996), hydroquinone (R^2 = 0.999) and BHT (R^2 = 0.999).

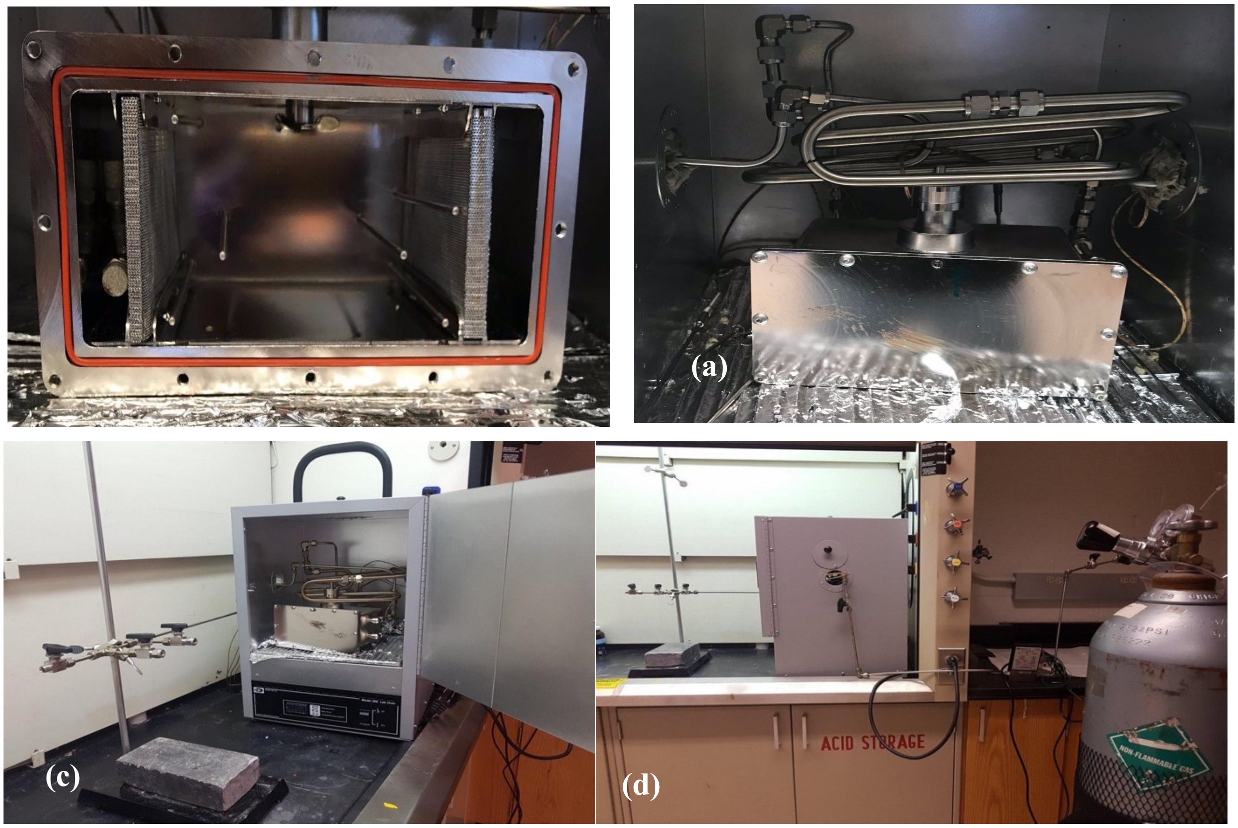


Fig. S1 Experimental setup for capturing post-cured chemical air emissions from cured composites: (a) inside the ETC; (b) enclosed ETC; (c) sampling ports connected to the ETC; (d) entire set-up

S3. RESULTS AND DISCUSSION

Table S2 Estimated mass of resin lost into atmosphere during CIPP manufacture

Year	*Reported CIPP Information*					*Estimated mass of resin lost if heating was applied for each CIPP application described the reference (kg)*
	Resin Type	***Resin Weight (kg)***	***Application***	***Monomer***	***Curing Method***	
2019 [27]	-	2.72×10^{5}	Storm sewer	-	-	2.41×10^{4}
2018 [28]	Isophthalic polyester	6.12×10^{4}	Sanitary sewer	Styrene	-	5.43×10^{3}
2014 [29]	Vinyl ester	7.94×10^{4}	Sewer	Styrene	-	7.04×10^{3}
2013 [30]	Unsaturated polyester	1.22×10^{8}	Sanitary and Storm	-	-	1.09×10^{7}
2012 [31]	Isophthalic polyester	4.54×10^{5}	-	-	Thermal	4.02×10^{4}
2012 [32]	Styrene-free vinyl	6.80×10^{4}	Storm sewer	-	-	6.04×10^{3}
2009 [33]	Vinyl ester	3.47×10^{5}	Sanitary sewer	Styrene	Hot water	3.08×10^{4}

Estimated mass of resin lost is equal to resin weight for each CIPP incidents reported in this Table times the average resin lost obtained in the present study when no vacuum was applied (8.87%).

Table S3 List of some tentatively identified compounds detected in uncured resin dissolved in methylene chloride with no dilution

Retention Time	Tentatively identified compound	IM	m/z	%Area (Average, STDEV)	
				Methylene chloride	**Hexane**
3.929, 3.933	Benzene, methyl-	3	1	3 replicates shown intensity < 5.00×10^{4}	2.85×10^{-2}, 1.20×10^{-1} 1 replicate shown intensity < 5.00×10^{4}
4.415, 4.418, 4.20, 4.395, 4.396, 4.397	1,3-Dioxolane, 2-ethyl-4-methyl-	5	7	$1.26\times10^{-1} \pm 7.64\times10^{-3}$	$2.70\times10^{-1} \pm 1.80\times10^{-1}$
4.617, 4.618, 4.621, 4.636, 4.638, 4.639	1,3-Dioxolane, 2-ethyl-4-methyl-	3	7	$9.81\times10^{-2} \pm 8.61\times10^{-3}$	$1.90\times10^{-1} \pm 1.20\times10^{-1}$
6.176, 6.177, 6.179, 6.192	Benzene, ethyl-	9	1	$5.76\times10^{-1} \pm 3.43\times10^{-2}$	1.68 ± 1.12
6.381	o-Xylene	4	1	3 replicates shown intensity < 5.00×10^{4}	2.82×10^{-1}, 5.90×10^{-2}
6.44, 6.449, 6.467	Maleic anhydride	5	4	$2.06\times10^{-1} \pm 1.25\times10^{-1}$	3 replicates shown intensity < 5.00×10^{4}
7.526, 7.528, 7.529, 7.54, 7.546, 7.551	Benzene, (1-methylethyl)-	7	05	1.30 ± 1.43	1.92 ± 1.21
7.785, 7.793. 7.797	Cyclooctane, ethyl-	4	9	$1.26\times10^{-1} \pm 1.11\times10^{-2}$	2 replicates shown intensity < 5.00×10^{4}
7.906, 7.907, 7.909, 7.912, 7.919, 7.923	Benzene, 2-propenyl-	6	17	$2.87\times10^{-1} \pm 2.84\times10^{-2}$	$5.30\times10^{-1} \pm 3.40\times10^{-1}$
8.04, 8.043, 8.044, 8.046, 8.054, 8.057	Benzene, propyl-	8	1	$2.57 \pm 3.09\times10^{-1}$	4.74 ± 2.97
8.182, 8.185, 8.186, 8.189, 8.196, 8.2	Benzene, 1-ethyl-3-methyl-	7	05	12.8 ± 1.93	22.6 ± 14.1
8.297, 8.301,8.303, 8.311, 8.314	Mesitylene	7	05	$3.54 \pm 4.60\times10^{-1}$	4.33 ± 2.74
8.494, 8.499, 8.5, 8.507, 8.51	Benzene, 1-ethyl-3-methyl-	6	05	$3.20 \pm 3.02\times10^{-1}$	4.19 ± 2.62
8.534, 8.535, 8.539, 8.547, 8.549	Benzene, (1-methylethenyl)-	7	18	$6.53\times10^{-1} \pm 1.38\times10^{-1}$	$1.17 \pm 7.2\times10^{-1}$

Retention Time	Tentatively identified compound	IM	m/z	%Area (Average, STDEV)	
				Methylene chloride	Hexane
8.589, 8.597, 8.599	Cyclohexane, 1-methyl-4-(1-methylethyl)-, trans-	4	5	$3.14\times10^{-2} \pm 4.33\times10^{-3}$	3 replicates shown intensity < 5.00×10^{4}
8.723, 8.728, 8.729, 8.73, 8.738, 8.741	Mesitylene	7	05	13.5 ± 1.99	21.9 ± 13.7
8.824, 8.829, 8.83, 8.837	Decane	3	7	$2.75\times10^{-1} \pm 6.34\times10^{-2}$	$3.10\times10^{-1} \pm 2.0\times10^{-1}$
8.959, 8.964, 8.965, 8.971, 8.973	Benzene, (2-methylpropyl)-	1	1	$1.07\times10^{-1} \pm 1.78\times10^{-2}$	$1.30\times10^{-1} \pm 8.00\times10^{-2}$
9.013, 9.018, 9.019, 9.025, 9.027	Benzene, (1-methyl-4-propyl)-	0	05	$9.53E\times10^{-2} \pm 1.56\times10^{-2}$	$1.20\times10^{-1} \pm 8.00\times10^{-2}$
9.199, 9.203, 9.204, 9.205, 9.211, 9.214	Benzene, 1,3,5-trimethyl-	4	05	$2.89 \pm 4.43\times10^{-1}$	3.53 ± 2.21
9.354, 9.355	Cyclohexane, butyl-	8	3	2.28×10^{-2}, 2.83×10^{-2}, 1 replicate shown intensity < 5.00×10^{4}	3 replicates shown intensity < 5.00×10^{4}
9.412, 9.417, 9.418, 9.419, 9.424, 9.427	Indane	5	17	$3.50\times10^{-1} \pm 5.11\times10^{-2}$	$6.60\times10^{-1} \pm 4.20\times10^{-1}$
9.654, 9.659, 9.666, 9.668	Benzene, 1-methyl-3-propyl-	4	05	$4.91\times10^{-1} \pm 7.46\times10^{-2}$	$6.30\times10^{-1} \pm 4.0\times10^{-1}$
9.764, 9.769, 9.77, 9.776, 9.778	Benzene, 1-ethyl-3,5-dimethyl-	4	19	$2.50\times10^{-1} \pm 4.13\times10^{-2}$	$2.10\times10^{-1} \pm 1.40\times10^{-1}$
9.840	Decane, 2-methyl-	8	7	$4.44\times10^{-2} \pm 1.13\times10^{-2}$	3 replicates shown intensity < 5.00×10^{4}
9.875	Oxirane, phenyl-	4	1	$2.95\times10^{-2} \pm 4.47\times10^{-3}$	2.46×10^{-1}, 2 replicates shown intensity < 5.00×10^{4}
9.968, 9.978	1,2-Propanedione, 1-phenyl-	4	05	3.56×10^{-2}, 7.45×10^{-2}, 1 replicate shown < 5.00×10^{4}	3 replicates shown intensity < 5.00×10^{4}
10.052, 10.058, 10.061	Benzene, 2-ethyl-1,4-dimethyl-	9	19	$1.13\times10^{-1} \pm 8.07\times10^{-2}$	9.49×10^{-2}, 9.69×10^{-2}

Retention Time	Tentatively identified compound	IM	m/z	%Area (Average, STDEV)	
				Methylene chloride	Hexane
10.167, 10.172, 10.173, 10.179, 10.181	Benzene, 1-ethyl-3,5-dimethyl-	3	19	$1.68\times10^{-1} \pm 3.49\times10^{-2}$	$1.90\times10^{-1} \pm 1.10\times10^{-1}$
10.351,10.355, 10.361, 10.363	Undecane	0	7	$8.10\times10^{-2} \pm 3.72\times10^{-3}$	2.76×10^{-2}, 2 replicates shown < 5.00×10^{4}
10.568, 10.572, 10.575 10.657, 10.688, 10.689	Hexanoic acid, 2-ethyl-	5	3	$3.02 \pm 2.96\times10^{-1}$	$5.20\times10^{-1} \pm 3.30\times10^{-1}$
10.74, 10.769, 10.786	Phosphoric acid, triethyl ester	5	9	$2.90\times10^{-2} \pm 7.86\times10^{-3}$	1 replicate shown intensity < 5.00×10^{4}
11.14, 11.16, 11.182, 11.21	Benzoic acid	6	05	$3.47\times10^{-2} \pm 2.01\times10^{-2}$	3 replicates shown intensity < 5.00×10^{4}
12.29	Ethanedione, diphenyl-	9	05	$6.00\times10^{-2} \pm 1.00\times10^{-2}$	3 replicates shown intensity < 5.00×10^{4}
12.565, 12.654, 12.706	Hydroquinone	3	10	$5.05\times10^{-1} \pm 1.46\times10^{-1}$	3 replicates shown intensity < 5.00×10^{4}
12.76, 12.763	4,7-Methano-1H-indenol, hexahydro-	1	6	3.96×10^{-2}, 3.06×10^{-2}	3 replicates shown intensity < 5.00×10^{4}
13.035, 13.064, 13.084	1,2-Ethanediol, 1-phenyl-	9	07	$7.32\times10^{-2} \pm 1.12\times10^{-2}$	3 replicates shown intensity < 5.00×10^{4}
13.214, 13.224, 13.231	1,2-Benzenedicarboxylic acid	4	04	$4.99 \pm 5.59\times10^{-1}$	3 replicates shown intensity < 5.00×10^{4}
15.294, 15.306, 15.318	p-tert.-Butylcatechol	9	91	$1.41\times10^{-1} \pm 2.12\times10^{-2}$	3 replicates shown intensity < 5.00×10^{4}
15.313, 15.314	2,4-Di-tert-butylphenol	0	91	1.57×10^{-1}	$9.77\times10^{-2} \pm 6.58\times10^{-2}$
15.37, 15.379, 15.38, 15.382, 15.384	2,6-bis (1,1-dimethylethyl)-4-methyl-phenol	2	05	$1.51 \pm 1.70\times10^{-1}$	$1.80\times10^{-1} \pm 1.20\times10^{-1}$

**Results shown only represent chromatogram signals greater than 50,000 a.u.; Styrene is not mentioned because it was excluded from MS program to protect MS from saturation and contamination due to very high concentration in the solution.*

S3.1. Volatile content in the cured composite cured at 65.5°C for 25 min

For the composite cured at Condition B (65.5°C / 25 min), the amount of volatile residual remained on the surface (2.63 ± 0.24 %) and in the depth (2.96 ± 0.13 %) was statistically similar to volatile content existed on the surface and in the depth of composites cured at Conditions A, C and D.

Table S4 The magnitude of volatile material that was released from cured composites during manufacture

Material description	**Volatile material emitted during manufacture**			
Composite manufacture conditions	**Condition A** **50 min, 65.5 ˚C**	**Condition B** **25 min, 65.5 ˚C**	**Condition C** **100 min, 65.5 ˚C**	**Condition A** **50 min, 93.3 ˚C**
Weight loss due to manufacture†, wt%				
Manufacture †, No vacuum ††				
	8.87 ± 1.67			
Manufacture, Vacuum applied				
	26.43 ± 1.73	25.87, 11.56*	21.95 ± 8.85	23.55 ± 3.77

*† Weight loss due to manufacture is equal to the difference between weight of resin mixture and two felts prior to curing and weight of composite obtained from the same materials after curing; * Weight loss was conducted for three replicate cured composites except for this condition where two replicates were measured; †† Weight loss at ambient conditions (no vacuum) was only measured at 65.5˚C for 50 min.*

Table S5 Density and porosity results of cured composites

	Curing conditions (Average ± STD)		
	50 min at 65.5˚C	***100 min at 65.5˚C***	***50 min at 93.3 ˚C***
Density (g/cm^3)	R_1: 1.19 ± 1.00×10^{-2}, R_2: 1.16, 1.17£	R_1: 1.15 ± 5.38×10^{-3}, R_2: 1.17 ± 7.44×10^{-3}	R_1: 1.14 ± 4.04×10^{-2}, R_2: 1.10§
Porosity (%)	R_1: 3.44×10^{-1} ± 2.03×10^{-1}, R_2: 2.52×10^{-1} ± 1.56×10^{-1}	R_1: 3.14×10^{-1} ± 1.63×10^{-1}, R_2: 5.70×10^{-1} ± 3.40×10^{-1}	R_1:6.04×10^{-1} ± 5.51×10^{-1}, R_2: 1.27 ± 4.79×10^{-1}

R is replicate; STD = standard deviation; £ Each cured composite replicate (i.e. R_1 and R_2) contained three replicate cubes to undergo density measurements except for this condition where two replicate cubes were measured; §Each cured composite replicate (i.e. R_1 and R_2) contained three replicate cubes to undergo density measurements except for this condition where one replicate cube was measured.

The single composite cured at ambient pressure showed no exothermic peak on the surface. No endothermic or exothermic peak was found on the second heating scan exhibiting no volatile residual and resin/initiator remained.

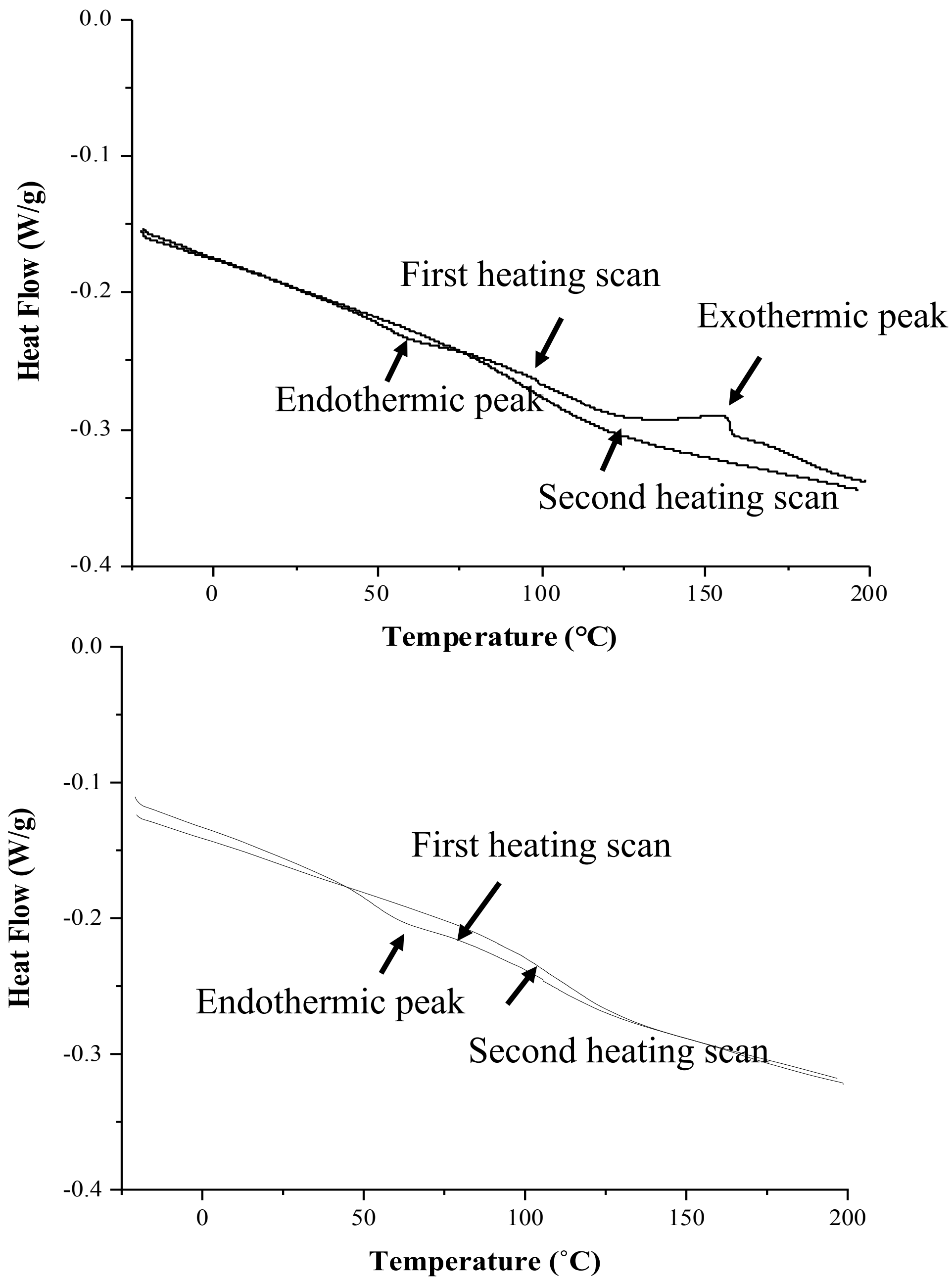


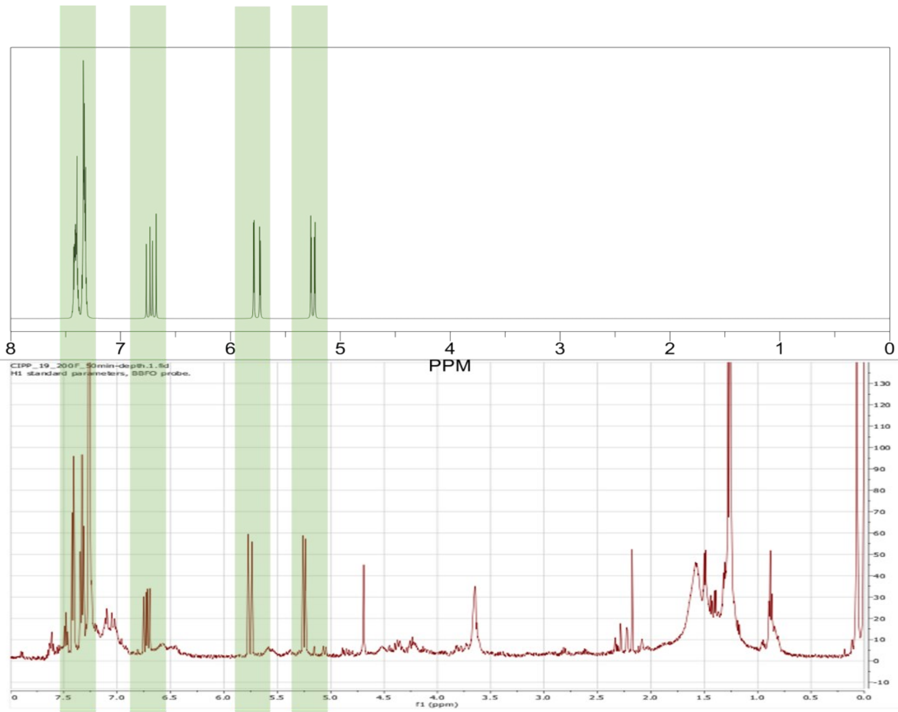
Fig. S2 DSC thermograms of cured composites cured at: (a) 65.5°C/50 min from surface; and (b) 93.3°C/50min from depth.

Table S6 Chemical Mass Loading (mg/kg) for the resin and new cured composites manufactured under different conditions in hexane

Chemical Detected	**Resin**	**Under Vacuum**				**No Vacuum**	**Studies in the Literature**	
		25 min at 65.5˚C	***50 min at 65.5˚C***	***100 min at 65.5˚C***	***50 min at 93.3˚C***	***50 min at 65.5˚C***	***CIPP***	***Resin Tube***
Hexane								
Styrene [CAR, EDR, HAP]	2.34×10^{5} ± 2.91×10^{4}	1.02×10^{4} ± 2.20×10^{2}	1.20×10^{3} ± 2.73×10^{2}	1.06×10^{3} ± 4.41×10^{2}	1.26×10^{3}± 3.05×10^{2}	5.22×10^{2} ± 1.81×10^{2}	(5.63×10^{2} - 1.47×10^{4})[25], (3.20×10^{1} – 9.30×10^{1})[26]	(5.72×10^{3}- 1.68×10^{5})[25], (4.45×10^{4} – 6.14×10^{4})[26]
Styrene oxide [CAR, HAP]	-	3.45×10^{1} ± 2.24×10^{1}	1.61×10^{1} ± 0.94	2.05×10^{1} ± 7.55	1.68×10^{1} ± 4.93	4.40×10^{1} ± 3.65×10^{1}	(1.10×10^{1} - 3.90×10^{1})[25]	(2.20×10^{1} - 5.50×10^{1})[25]
Benzaldehyde	-	4.91×10^{1} ± 3.32×10^{1}	3.18×10^{1} ± 3.34×10^{1}	7.58×10^{1} ± 2.89×10^{1}	2.06×10^{1} ± 2.45×10^{1}	1.14×10^{1} ± 8.54×10^{1}	(1.40×10^{1} – 9.40×10^{1})[26]	-
1,3,5-TMB	2.27×10^{1} ± 4.00	3.35 ± 0.87	2.96 ± 0.48	3.61 ± 1.06	3.26 ± 0.58	7.13×10^{1}	(1.70-2.40)[25]	(5.10- 5.40×10^{1})[25]
1,2,4-TMB	1.07×10^{2} ± 2.52×10^{1}	1.54×10^{1} ± 4.44	1.83×10^{1} ± 3.15	1.94×10^{1} ± 5.86	1.70×10^{2} ± 5.16	9.08 ± 4.11	(2.30-1.20×10^{1})[25]	(1.10×10^{1} - 1.88×10^{2})[25]
Benzoic Acid	1 replicate shown<5.00×10^{4} & SIM<90	1.51×10^{2}± 5.37×10^{1}	1.41×10^{2} ± 1.25×10^{1}	1.80×10^{2} ± 2.17×10^{1}	1.68×10^{2} ± 2.74×10^{1}	1.10×10^{2} ± 2.59×10^{1}	-	-
1-tetradecanol	-	2.88×102± 2.93×101	3.14×102 ± 2.99×101	3.49×102 ± 1.30×102	3.38×102 ± 5.26×101	3.04×102 ± 6.07×101	(4.33×10^{2} - 8.72×10^{2})[26]	

Chemical Detected	Resin	Under Vacuum				No Vacuum	Studies in the Literature	
		25 min at 65.5˚C	***50 min at 65.5˚C***	***100 min at 65.5˚C***	***50 min at 93.3˚C***	***50 min at 65.5˚C***	***CIPP***	***Resin Tube***
Hexane								
N-Propylbenzene	$2.03\times10^1 \pm 5.19$	3.48 ± 0.80	3.69 ± 0.42	4.03 ± 0.99	3.58 ± 0.94	3.40 ± 0.57	$(0.43\text{-}1.20\times10^1)$[25]	$(2.40\times10^1\text{-}4.90\times10^1)$[25]
2-Propenylbenzene	$2.31 \pm 5.39\times10^1$	-	-	-	-	-	-	-
Hydroquinone [CAR*, HAP]	-	-	1 replicate shown < 5.00×10^4 & SIM < 90	-	-	2 replicates shown < 5.00×10^4 & SIM < 90	-	-
1-Ethyl-3-methylbenzene	$1.27\times10^2 \pm 2.84\times10^1$	3 replicates shown > 5.00×10^4 & SIM > 90	3 replicates shown > 5.00×10^4 & SIM > 90	3 replicates shown > 5.00×10^4 & SIM > 90	3 replicates shown > 5.00×10^4 & SIM > 90	3 replicates shown > 5.00×10^4 & SIM > 90	-	-
2-Ethylhexanoic acid	$1.23\times10^1 \pm 2.43$	2 replicates shown < 5.00×10^4 & SIM < 90	3 replicates shown < 5.00×10^4 & SIM < 90	3 replicates shown < 5.00×10^4 & SIM < 90	3 replicates shown < 5.00×10^4 & SIM < 90	3 replicates shown < 5.00×10^4 & SIM < 90	-	-
BHT	1.41 ± 0.24	-	-	-	-	-	$(4.90\text{-}9.40)$[25]	$(3.10\times10^1\text{-}8.90\times10^1)$[25]

Chemical Detected	**Resin**	**Under Vacuum**				**No Vacuum**	**Studies in the Literature**	
		25 min at 65.5˚C	***50 min at 65.5˚C***	***100 min at 65.5˚C***	***50 min at 93.3˚C***	***50 min at 65.5˚C***	***CIPP***	***Resin Tube***
Hexane								
Sum	2.34×10^5	1.57×10^3	1.73×10^3	1.72×10^3	1.82×10^3	1.07×10^3	(6.22×10^2 -1.47×10^4)[25], (8.37×10^2 -1.57×10^3)[26]	(5.98×10^3 -1.69×10^5)[25], (4,45×10^4 - 3.20×10^5)[26]


PPM
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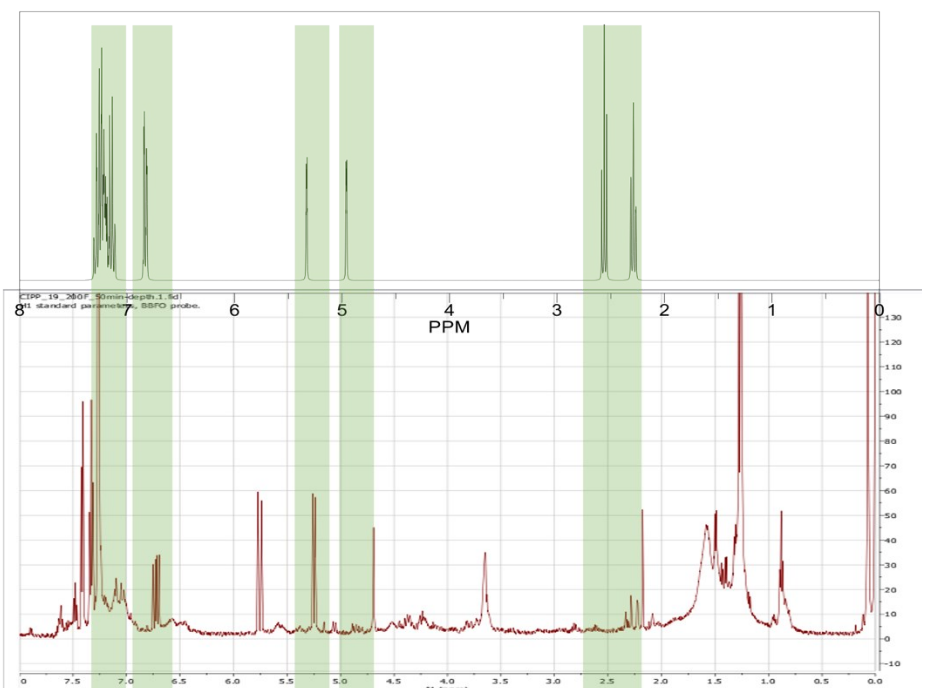
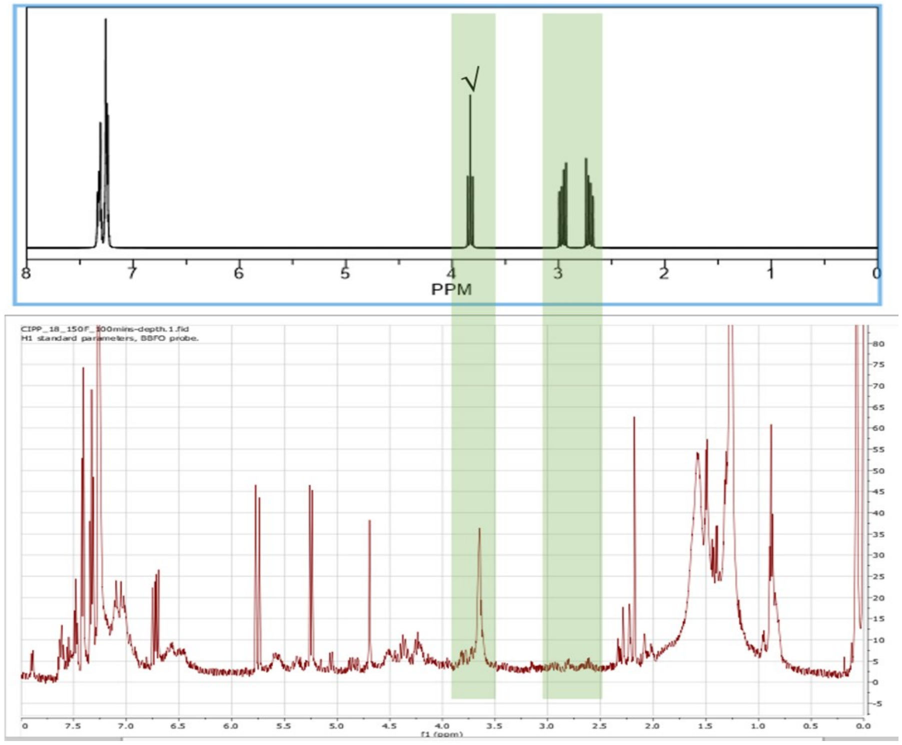
H1 standard parameters, BBFO probe.
f1 (ppm)

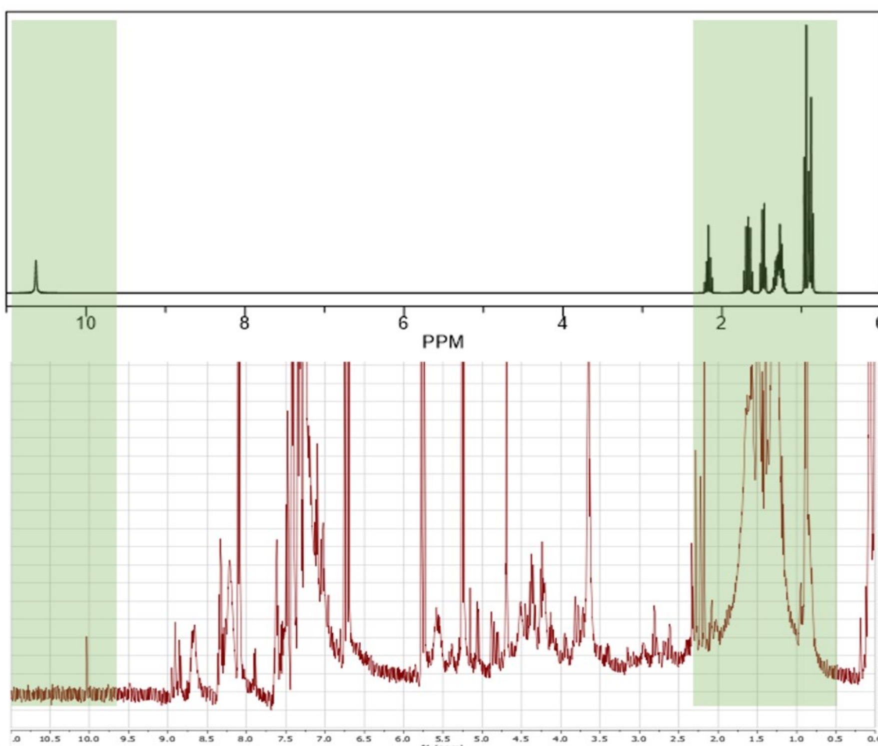
(a)


PPM
CIPP_19_200F_50min-depth.1.fid
H1 standard parameters, BBFO probe.
f1 (ppm)

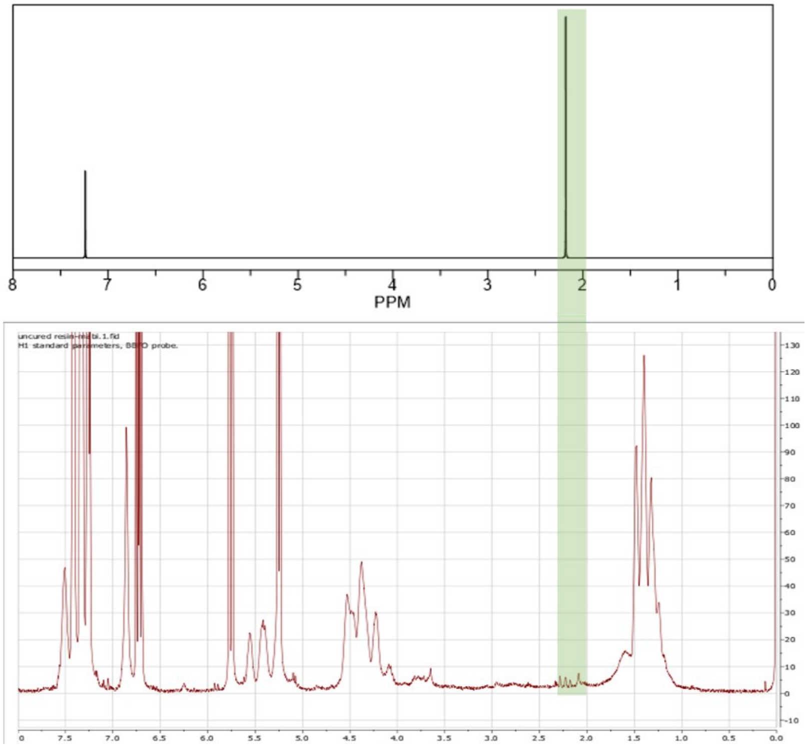
(b)



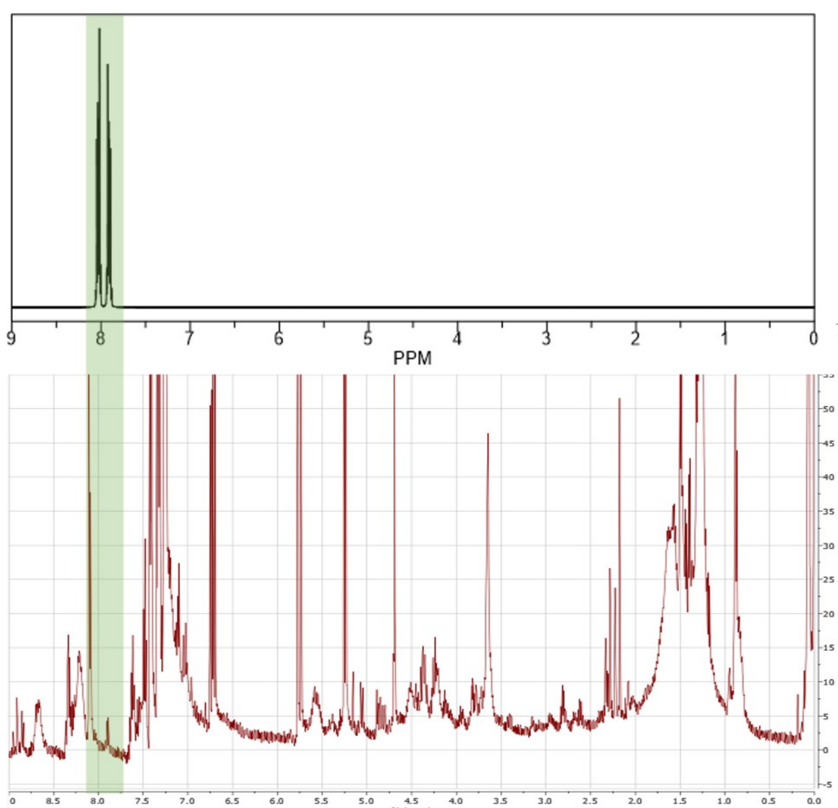
(c)



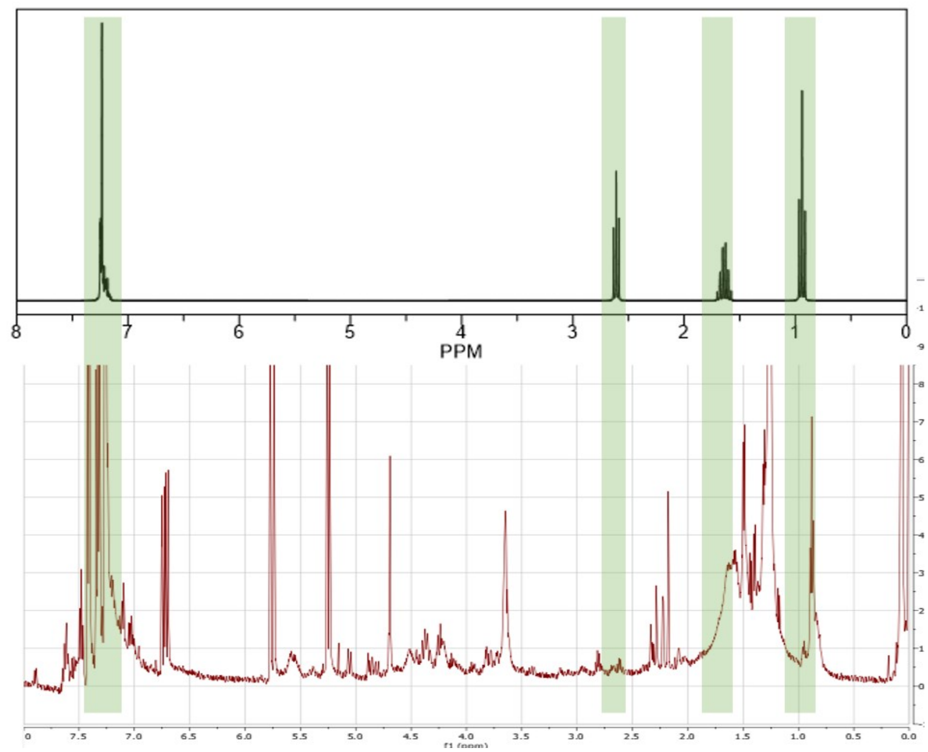
(d)


PPM
uncured resin-rmbi.1.fid
H1 standard parameters, BBFO probe.

(e)

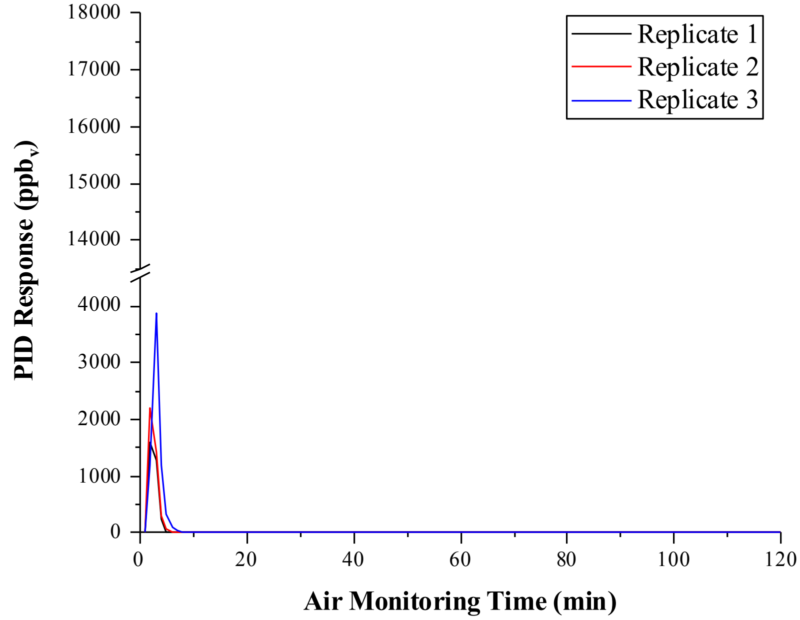

PPM
f1 (ppm)

(f)

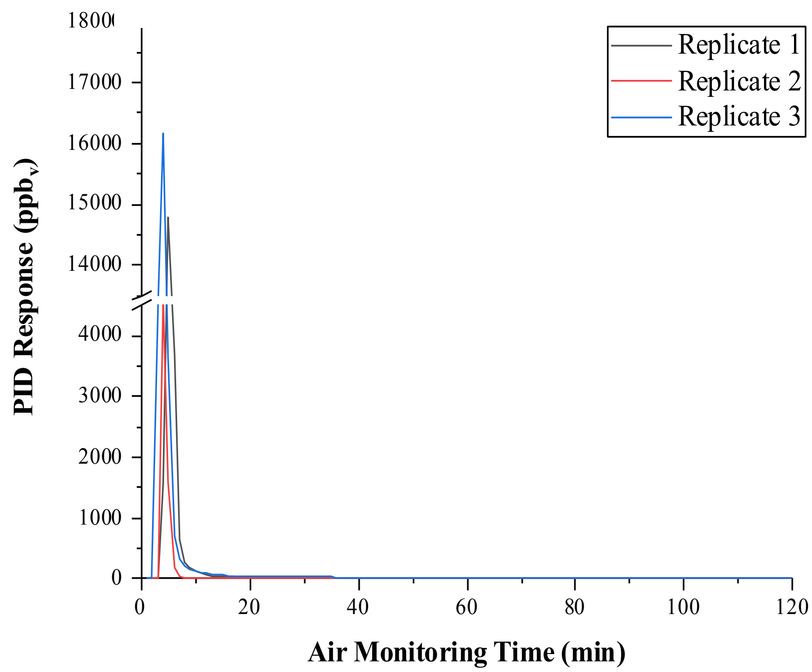


(g)

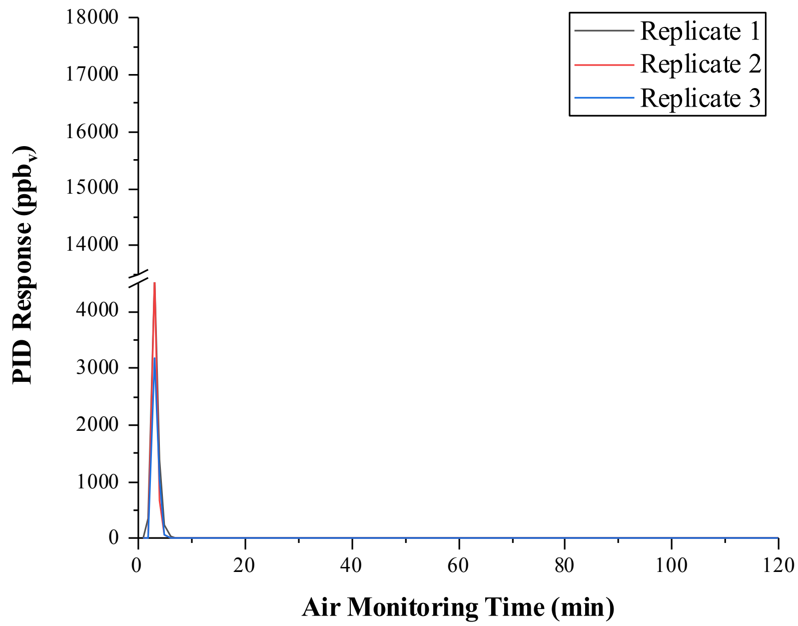
Fig. S3 HNMR images of compounds detected in uncured resin and cured composites at different curing conditions: (a) Styrene, (b) 2,4-diphenyl-1-butene (styrene dimer), (c) styrene oxide, (d) 2-ethylhexanoic acid, (e) 1,3,5-trimethylbenzene, (f) phthalate anhydride, (g) propylbenzene


18000
17000
16000
15000
14000
4000
3000
2000
1000
0
0
20
40
60
80
100
120
PID Response (ppb$_v$)
Air Monitoring Time (min)
Replicate 1
Replicate 2
Replicate 3

(a)


17000
16000
15000
14000
4000
3000
2000
1000
0
0
20
40
60
80
100
120
PID Response (ppb$_v$)
Air Monitoring Time (min)
Replicate 1
Replicate 2
Replicate 3

(b)



(c)

Fig. S4 PID air monitoring results from cured composites (a) 65.5 °C/50 min, (b) 65.5 °C/10 min and (c) 93.3 °C/50 min during 2 hr ventilation.

Table S7 Styrene normalized weight and concentration captured during 2hr dynamic air monitoring

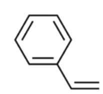
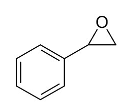
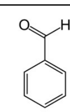
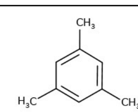
	Time (min)	*Normalized styrene weight (ng/cm²), Concentration (ppm$_v$) Average ± STD*		
		65.5 C/50 min	***65.5 C/ 100 min***	***93.3 C/ 50 min***
Dynamic	0	1.25 ± 1.20, 2.19 ± 1.47	4.81 ± 3.87, 6.11 ± 4.90	1.05 ± 1.63, 1.30 ± 2.04
	5	$5.34\times10^{-2} \pm 5.30\times10^{-2}$, $6.92\times10^{-2} \pm 6.93\times10^{-2}$	$3.26\times10^{-2} \pm 1.40\times10^{-2}$, $4.13\times10^{-2} \pm 1.77\times10^{-2}$	$1.64\times10^{-2} \pm 3.75\times10^{-3}$, $2.05\times10^{-2} \pm 4.53\times10^{-3}$
	10	$9.42\times10^{-3} \pm 4.52\times10^{-3}$, $1.21\times10^{-2} \pm 6.01\times10^{-3}$	$1.49\times10^{-2} \pm 1.58\times10^{-2}$, $1.89\times10^{-2} \pm 1.98\times10^{-2}$	$1.11\times10^{-3} \pm 1.92\times10^{-3}$, $1.38\times10^{-3} \pm 2.38\times10^{-3}$
	20	$6.05\times10^{-3} \pm 2.98\times10^{-3}$, $7.79\times10^{-3} \pm 3.95\times10^{-3}$	$9.30\times10^{-3} \pm 9.17\times10^{-3}$, $1.18\times10^{-2} \pm 1.15\times10^{-2}$	$7.61\times10^{-4} \pm 8.90\times10^{-4}$, $9.46\times10^{-4} \pm 1.10\times10^{-3}$
	40	$3.54\times10^{-3} \pm 2.86\times10^{-3}$, $4.60\times10^{-3} \pm 3.72\times10^{-3}$	$7.49\times10^{-3} \pm 8.42\times10^{-3}$, $9.45\times10^{-3} \pm 1.05\times10^{-2}$	$1.14\times10^{-4} \pm 1.97\times10^{-4}$, $1.42\times10^{-4} \pm 2.45\times10^{-4}$
	60	$3.79\times10^{-3} \pm 1.02\times10^{-3}$, $4.87\times10^{-3} \pm 1.39\times10^{-3}$	$8.46\times10^{-3} \pm 8.45\times10^{-3}$, $1.07\times10^{-2} \pm 1.06\times10^{-2}$	$1.14\times10^{-4} \pm 1.97\times10^{-4}$, $1.42\times10^{-4} \pm 2.45\times10^{-4}$
	80	$2.62\times10^{-3} \pm 2.44\times10^{-3}$, $3.39\times10^{-3} \pm 3.17\times10^{-3}$	$6.81\times10^{-3} \pm 7.66\times10^{-3}$, $8.59\times10^{-3} \pm 9.58\times10^{-3}$	$1.14\times10^{-4} \pm 1.97\times10^{-4}$, $1.42\times10^{-4} \pm 2.45\times10^{-4}$
	100	$3.49\times10^{-3} \pm 1.27\times10^{-3}$, $4.48\times10^{-3} \pm 1.70\times10^{-3}$	$6.62\times10^{-3} \pm 7.79\times10^{-3}$, $8.38\times10^{-3} \pm 9.78\times10^{-3}$	$1.14\times10^{-4} \pm 1.97\times10^{-4}$, $1.42\times10^{-4} \pm 2.45\times10^{-4}$
	120	$2.35\times10^{-3} \pm 1.75\times10^{-3}$, $3.05\times10^{-3} \pm 2.29\times10^{-3}$	$8.15\times10^{-3} \pm 7.82\times10^{-3}$, $1.03\times10^{-2} \pm 9.83\times10^{-3}$	$1.14\times10^{-4} \pm 1.97\times10^{-4}$, $1.42\times10^{-4} \pm 2.45\times10^{-4}$

STD = standard deviation

S3.2. The most abundant chemical in cured composites

As expected, styrene with the highest loading magnitude (9.74×10^3 - 2.07×10^4 mg/Kg) constituted a significant portion of cured composites. This compound also showed higher vapor pressure (i.e. 6.40 mmHg at 25 ^{o}C) and subsequently, higher volatility compared with other chemicals confirmed in the cured composite extraction. The order of these chemicals with higher vapor pressure (i.e. higher volatility) to lower vapor pressure (i.e. lower volatility) includes: styrene > *N*-propylbenzene > 3-ethyl-1-methylbenzene > 1,3,5-TMB > 1,2,4-TMB > 2-propenylbenzene > benzaldehyde > styrene oxide > 2-ethylhexanoic acid > BHT > benzoic Acid > 1-tetradecanol > hydroquinone. Therefore, it could be assumed that considerable amount of chemicals discharged into air during composite manufacturing contains styrene.

Table S8 Physical and chemical properties of confirmed organic compounds in the uncured resin tube and cured composite

Compound	Chemical Formula	MW, g/mol	Chemical Structure	Vapor Pressure (mmHg 25^{o}C)
Styrene	C_8H_8	104.15		6.40
Styrene oxide	C_8H_8O	120.15		0.30
Benzaldehyde	C_7H_6O	106.13		1.27
1,3,5-TMB	C_9H_{12}	120.20		2.48

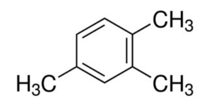
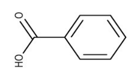
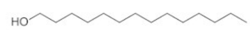
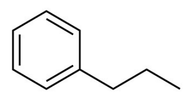
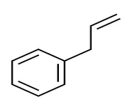
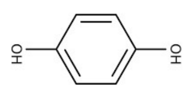
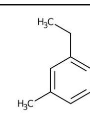
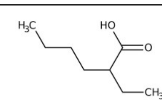
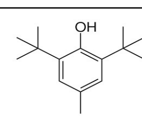
Compound	Chemical Formula	MW, g/mol	Chemical Structure	Vapor Pressure (mmHg 25^{o}C)
1,2,4-TMB	C_9H_{12}	120.20		2.10
Benzoic Acid	$C_7H_6O_2$	122.12		7×10^{-4}
1-Tetradecanol	$C_{14}H_{30}O$	214.39		1.1×10^{-4}
***N*-Propylbenzene**	C_9H_{12}	120.20		3.42
2-Propenylbenzene	C_9H_{10}	118.18		1.69
Hydroquinone	$C_6H_6O_2$	110.11		1.90×10^{-5}
3-Ethyl-1-methylbenzene	C9H11	120.19		3.04
2-Ethylhexanoic acid	C8H16O2	144.214		< 7.50×10^{-3}
BHT	C15H24O	220.36		5.20×10^{-3}

Table S9 Endothermic/exothermic temperature observed in new cured composites based on different curing conditions.

Parameter	**Curing condition and endothermic/exothermic temperature, °C**			
	Condition A **50 min, 65.5˚C**	**Condition B** **100 min, 65.5˚C**	**Condition C** **50 min, 93.3˚C**	**Condition D** **25 min, 65.5˚C**
	Endothermic/Exothermic Temperature	**Endothermic/ Exothermic Temperature**	**Endothermic/ Exothermic Temperature**	**Endothermic/ Exothermic Temperature**
After Manufacture, No vacuum				
Surface	£ 62°C, 64°C, 65°C / -	-	-	-
Depth	££ 60°C, 63°C, 64°C, 68°C / 153.5°C 154.5°C	-	-	-
After Manufacture, Vacuum applied				
Surface	€ 58°C, 59°C, 60°C, 64°C, 65°C / 154°C, 154.5°C, 156.5°C, 159°C	§ 57°C, 58°C, 58.5°C, 64°C / 151.3°C, 153.5°C, 155°C, 155.5°C, 159.5°C	¥ 60°C, 61.8°C, 64°C / 154°C, 159.5°C, 164°C, 168°C	†
Depth	€€ 56°C, 59°C, 60°C / 158°C, 160°C, 160.6°C, 161.5°C, 167°C, 168°C	§§ 58°C, 59°C, 62°C, 64°C / 158.5°C, 159.5°C, 163°C, 164°C, 165°C	¥¥ 56.5°C, 58°C, 60°C, 62°C, 64°C / 152°C, 163.5°C, 164°C, 167.5°C, 168.5°C, 172°C	‡ 64.5°C, 66°C, 67°C, 68°C / 161°C, 164.5°C

Initial volatile content of the resin was 39 ± 1.74 %; -: Not measured. The following symbols indicate the number of replicates that showed endothermic peak at approximately 65°C and exothermic peak at 140-160°C per the total number of replicates: £ endothermic peak: 8/8, exothermic peak: 0/9; ££ endothermic peak: 6/9, exothermic peak: 2/9; † endothermic peak:, exothermic peak:; ‡ endothermic peak: 8/9, exothermic peak: 3/9; € endothermic peak: 8/9, exothermic peak: 5/9; €€ endothermic peak: 4/9, exothermic peak: 7/9; § endothermic peak: 4/9, exothermic peak: 5/9; §§ endothermic peak: 3/8, exothermic peak: 7/8; ¥ endothermic peak: 5/9, exothermic peak: 4/9; ¥¥ endothermic peak: 6/9, exothermic peak: 6/9

S4. REFERENCES SPECIFIC TO THE ELECTRONIC SUPPORTING INFORMATION

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