



# 不止“火安全” ...

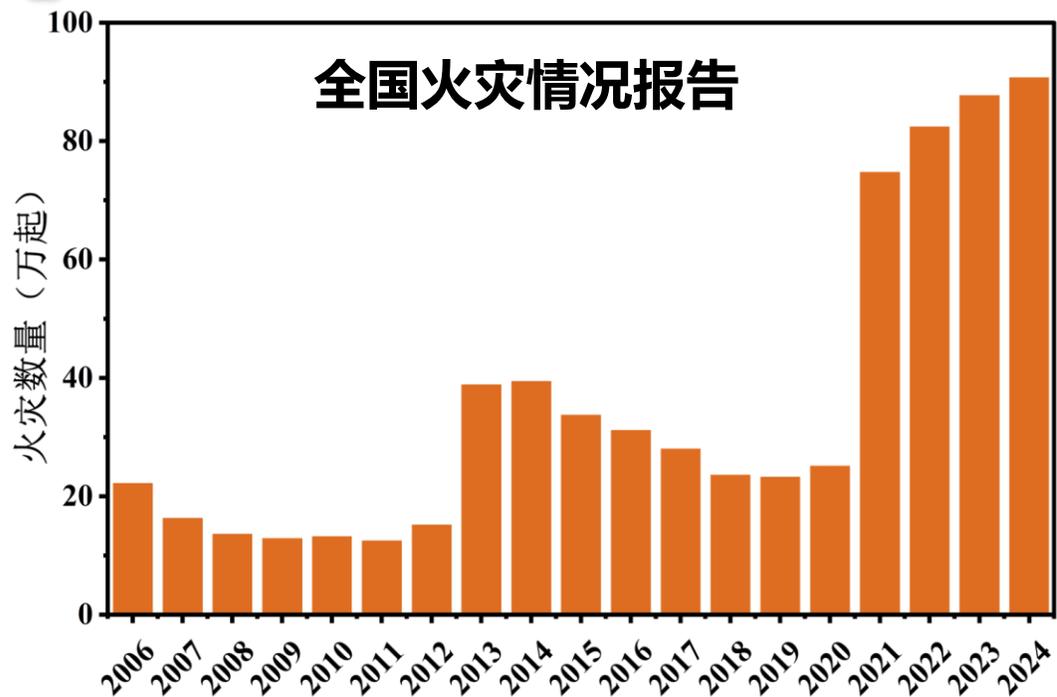
——几种典型纺织品阻燃改性的新探索

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中国塑料加工工业协会阻燃材料及应用专业委员会

# 纺织品的易燃性及其危害



159死 79伤

香港大埔 大型住宅火灾  
2025年11月26日



42死 2伤

河南安阳 凯信达商贸 厂房火灾  
2022年11月21日

事故原因：火源引燃周围纺织品或装饰物

- LOI低
- 易于被点燃
- 火焰传播迅速
- 热释放量大

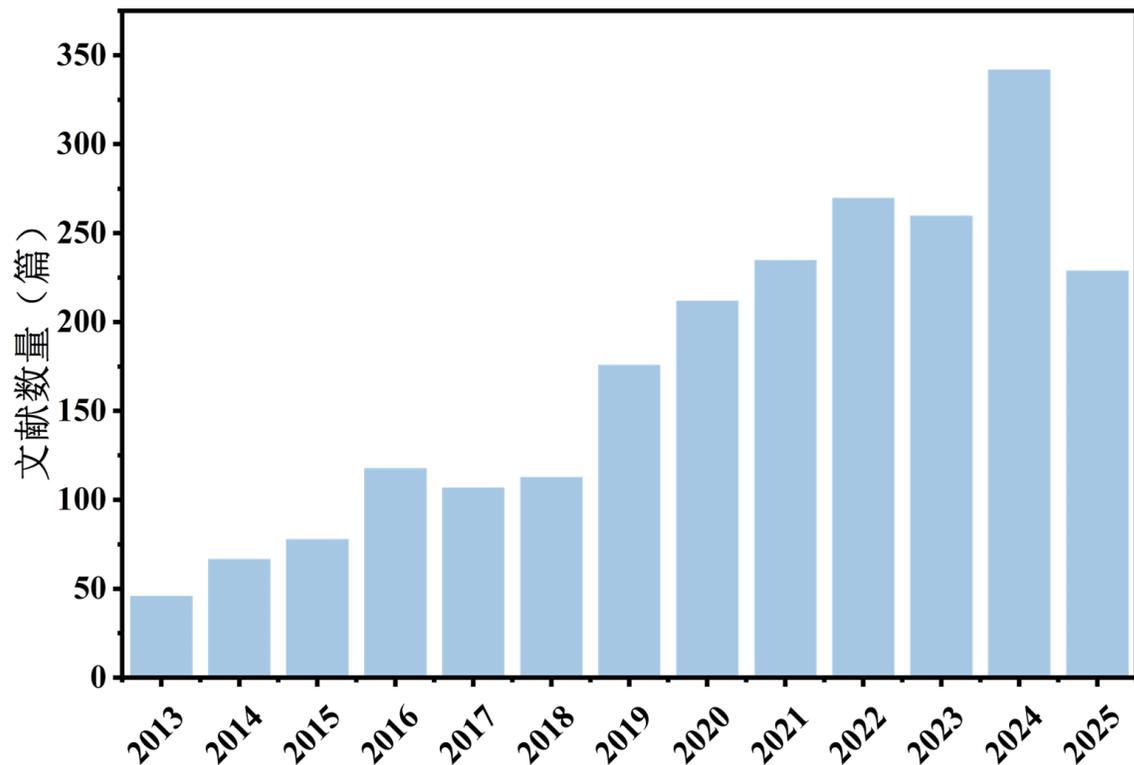
提高阻燃性能



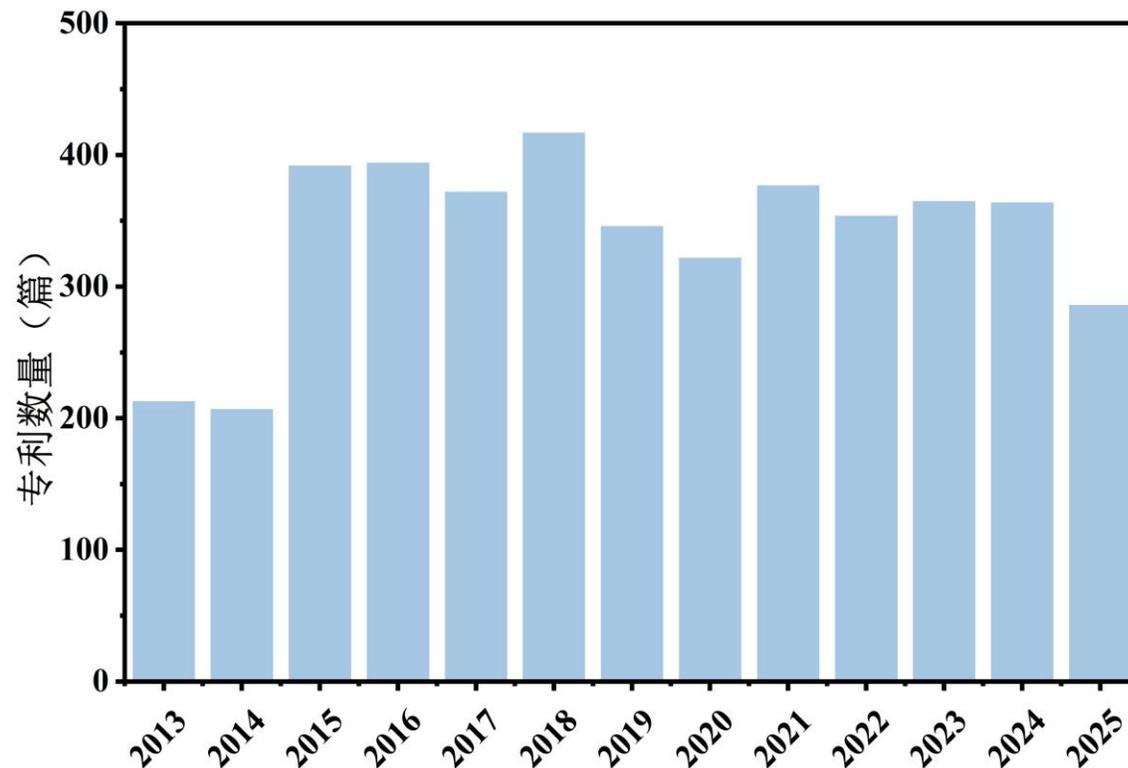
防火阻燃型纺织品



传统型纺织品



来源web of science, 关键词flame retardant fabric

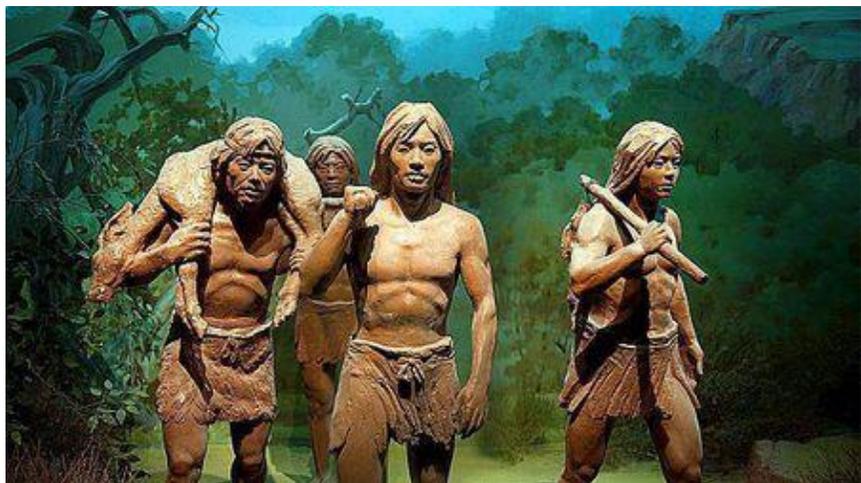


来源万方, 关键词阻燃织物

**解决了材料火安全的问题，  
是否就足够安全了？**



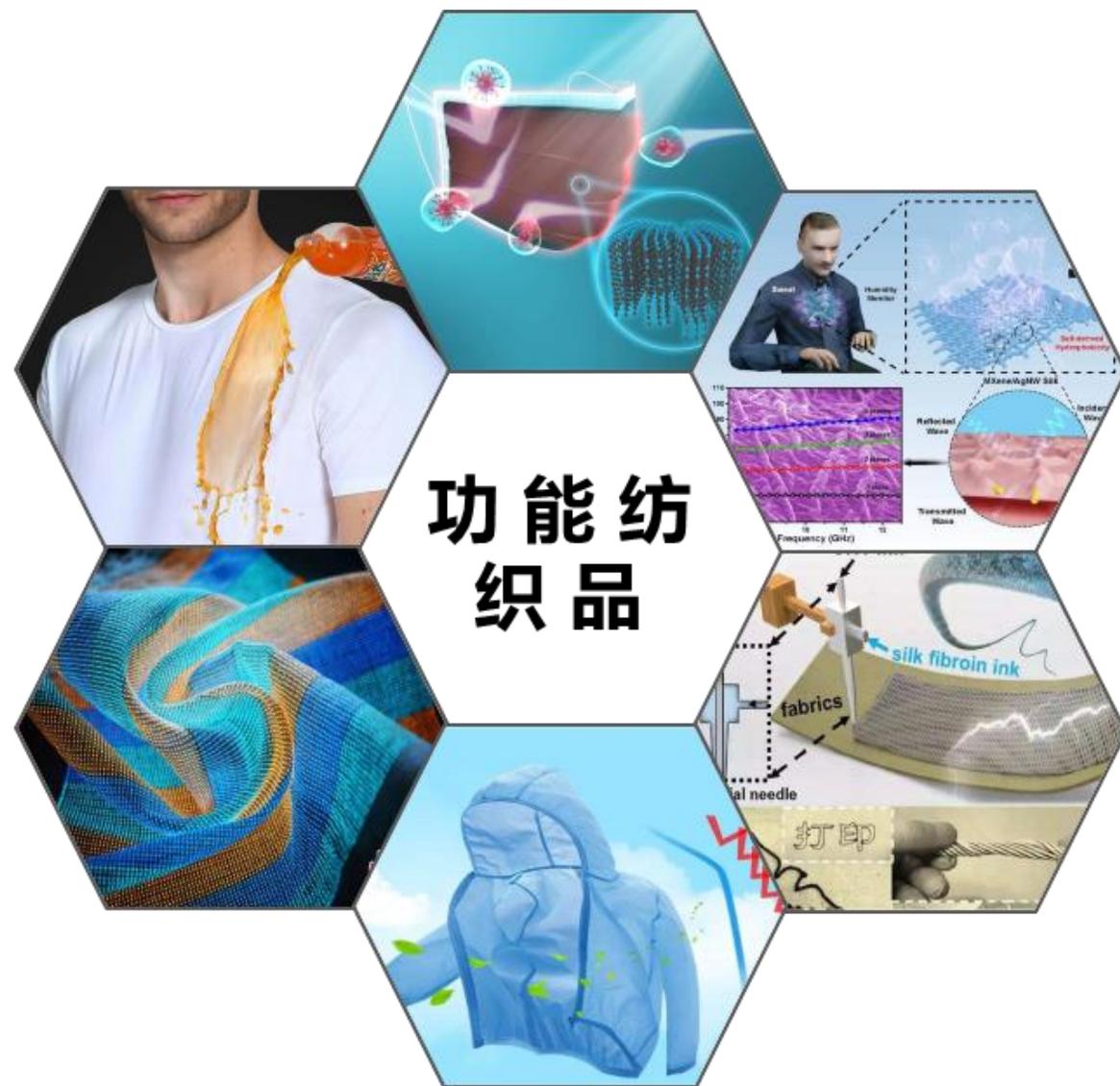




遮体



保暖



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02

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多基体通用

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多功能

01

**低毒  
低刺激**

# 低毒、低刺激

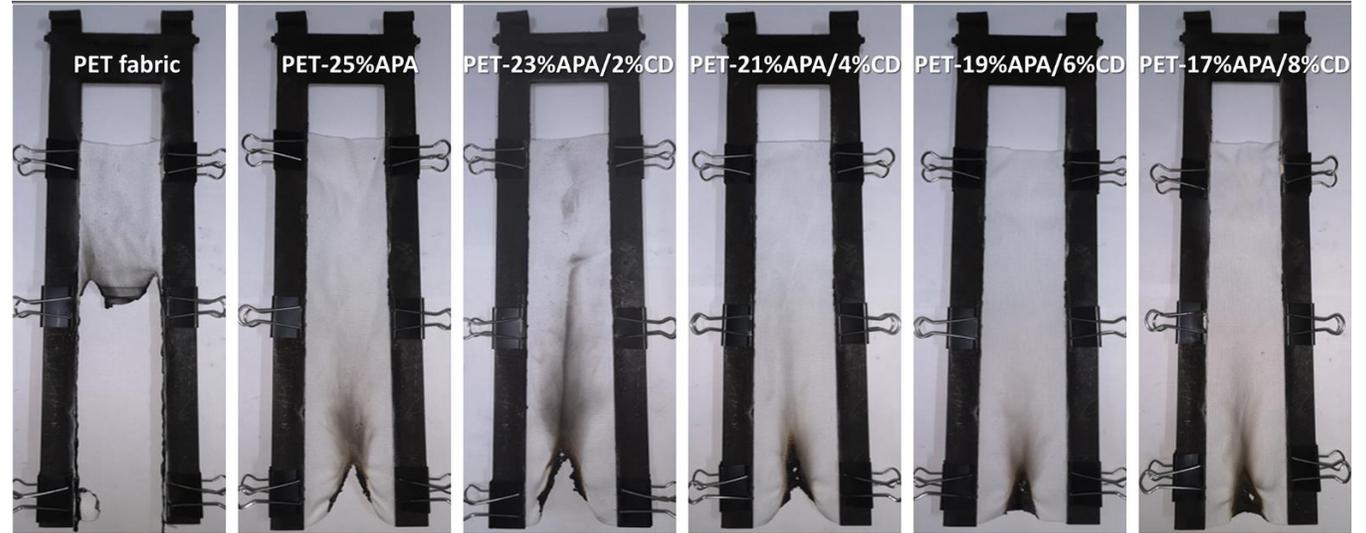
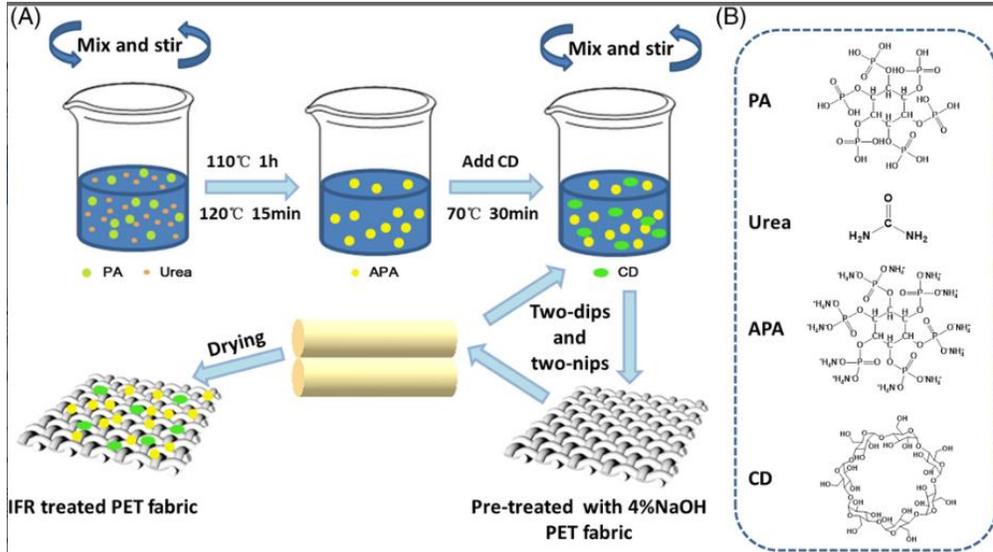


## 我们不生产水 我们只是大自然的搬运工

农夫山泉坚守“从不使用城市自来水”的理念，始终坚持水源地建厂，水源地生产，确保每一瓶农夫山泉的天然健康品质。

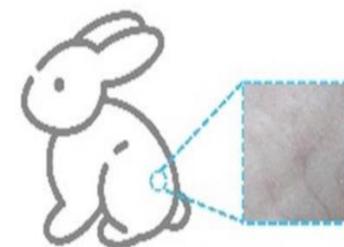
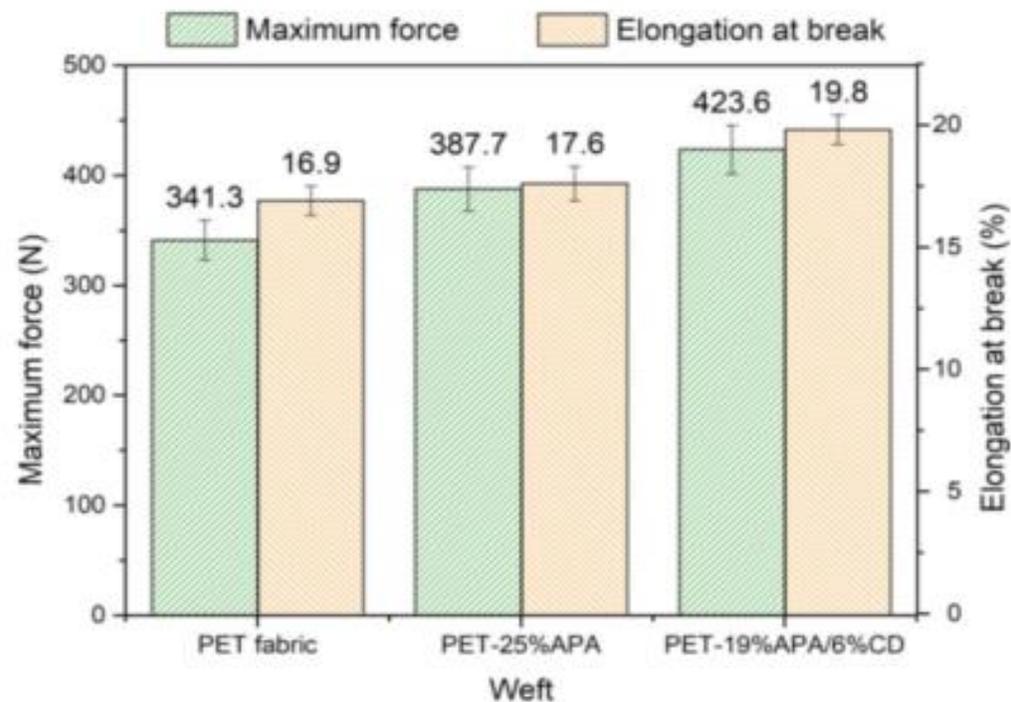
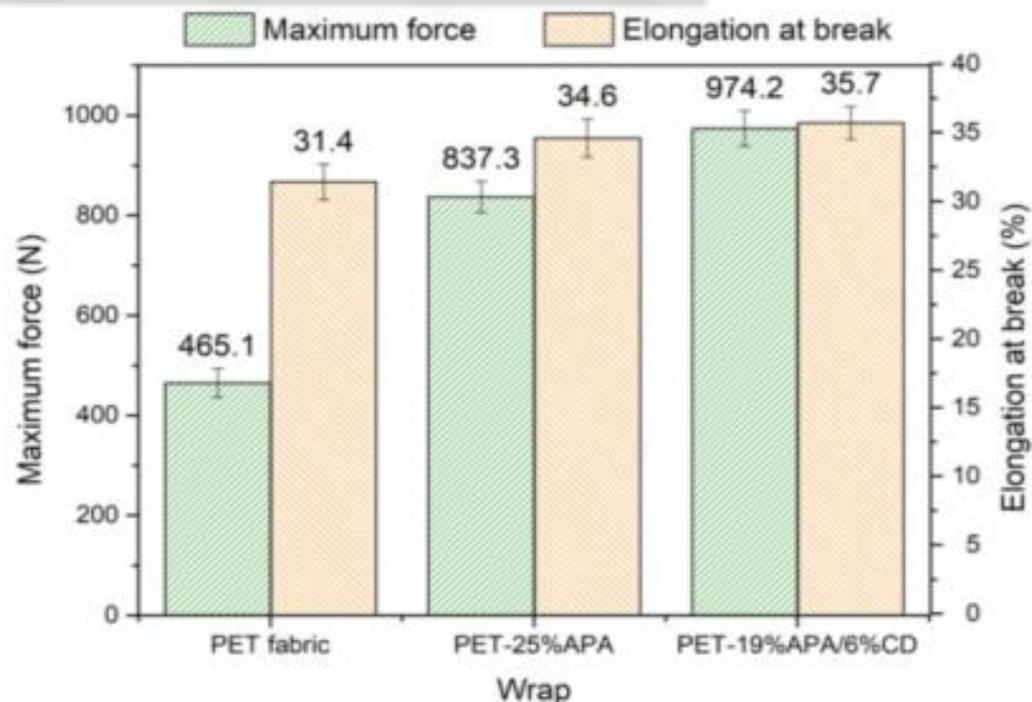


## 植酸铵 / 环糊精 全生物基涂层 → 涤纶

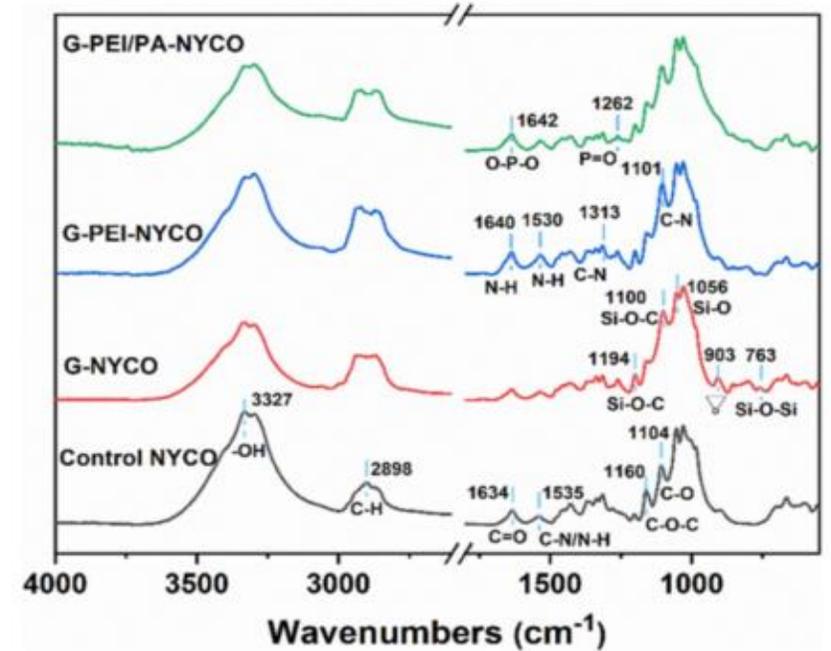
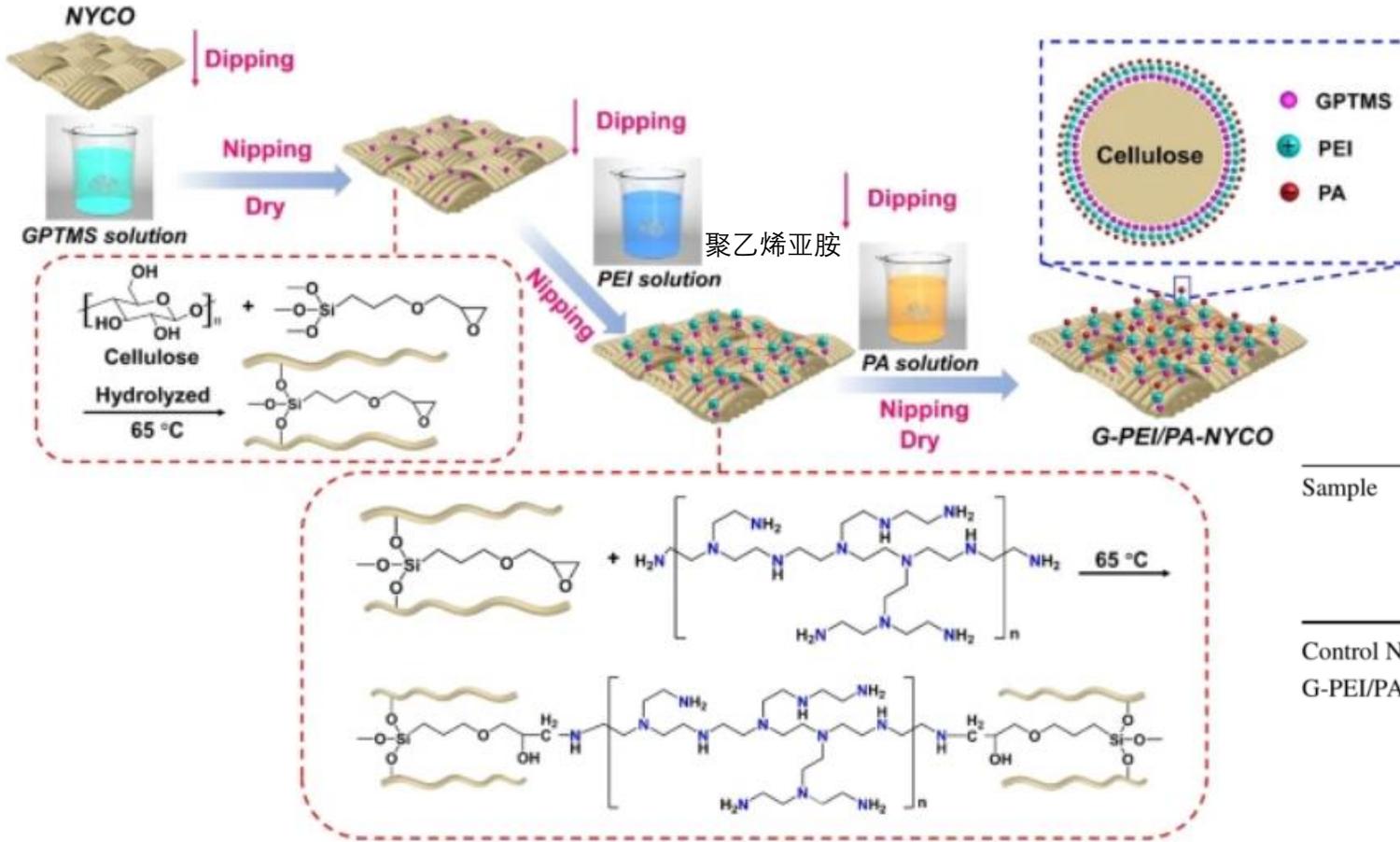


Sample	W-G/%	LOI/%	Vertical flammability test		
			Damaged length/cm	After flame time/s	Dripping
PET fabric	-	19.0 ± 0.5	24.5 ± 3.7	41.0 ± 5.8	Yes
PET-25%APA	25.8 ± 1.3	27.8 ± 0.2	5.1 ± 2.5	4.4 ± 3.1	No
PET-23%APA/2%CD	29.4 ± 1.6	28.1 ± 0.2	5.8 ± 2.8	6.8 ± 2.5	No
PET-21%APA/4%CD	31.2 ± 1.9	28.6 ± 0.3	6.5 ± 1.7	0	No
PET-19%APA/6%CD	33.7 ± 2.2	29.5 ± 0.2	4.4 ± 1.1	0	No
PET-17%APA/8%CD	35.0 ± 2.4	28.9 ± 0.3	4.1 ± 0.8	0	No

# 低毒、低刺激

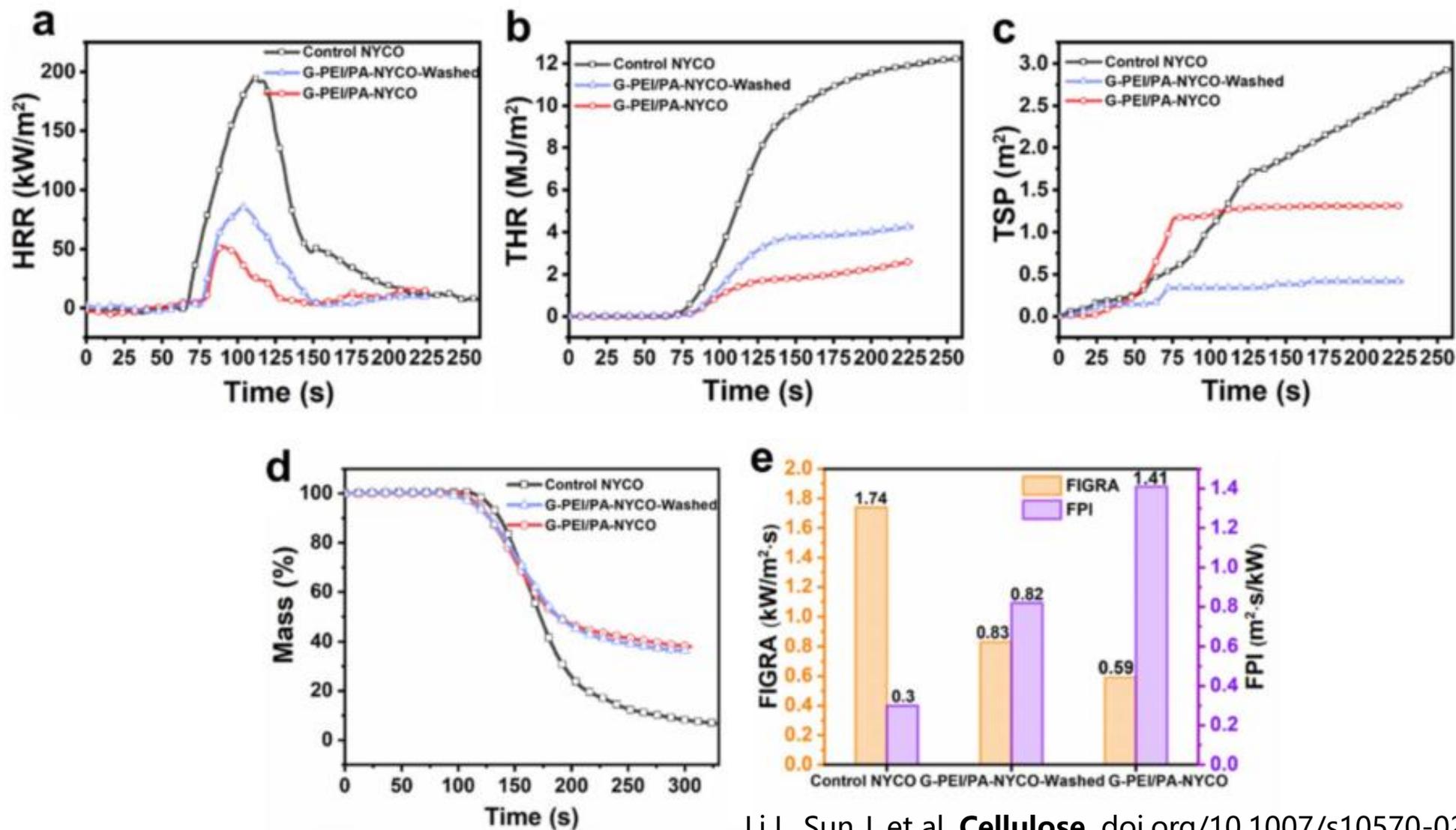


## PEI/植酸 → 锦棉混纺



Sample	LCs	Weight gain (wt%)	LOI (%)	Vertical burning test		
				After-flame time (s)	Afterglow time (s)	Damaged length (mm)
Control NYCO	-	-	18.5±0.2	11±1	19±1	300±0
G-PEI/PA-NYCO	0	19.8±0.2	29.8±0.1	0	0	75±2
	5	18.2±0.2	29.0±0.1	0	0	87±3
	10	17.8±0.2	28.0±0.1	0	0	96±3
	15	17.2±0.2	26.7±0.1	0	0	110±3
	20	16.5±0.2	25.8±0.1	0	0	180±4
PEI/PA-NYCO	0	17.8±0.4	26.3±0.2	0	0	175±6
	5	13.2±0.4	24.3±0.2	8±1	0	300±0

## PEI/植酸 → 锦棉混纺



## PEI/植酸 → 锦棉混纺

Test group



Control group



Day1

Day2

Day3

Day4

Day5

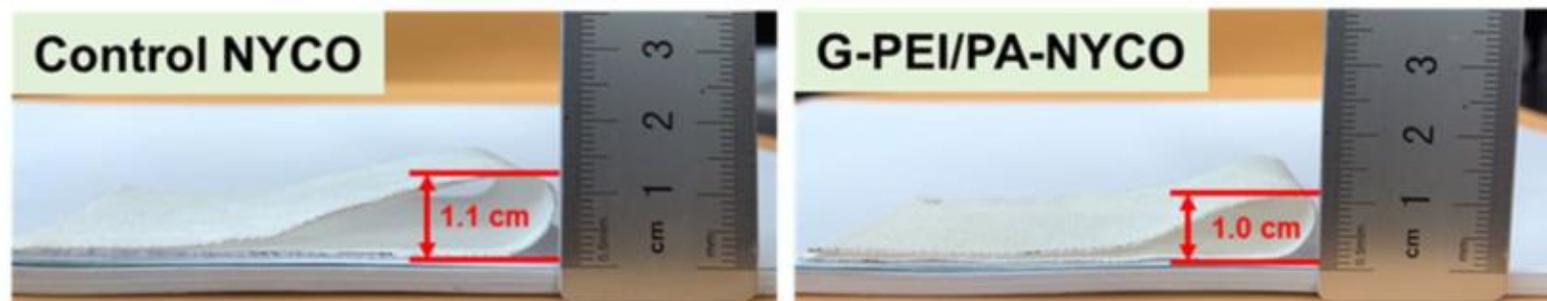
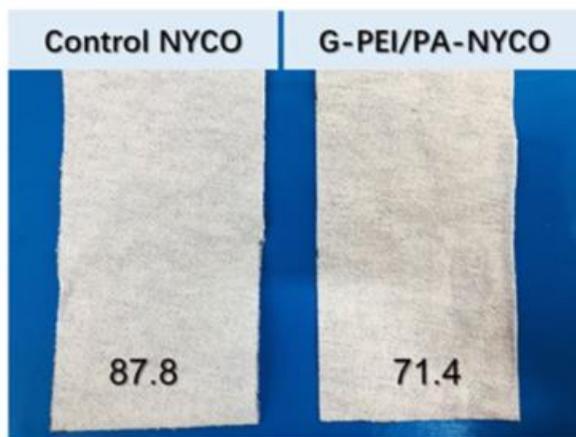
Day6

Day7

Day8

Day9

Day10

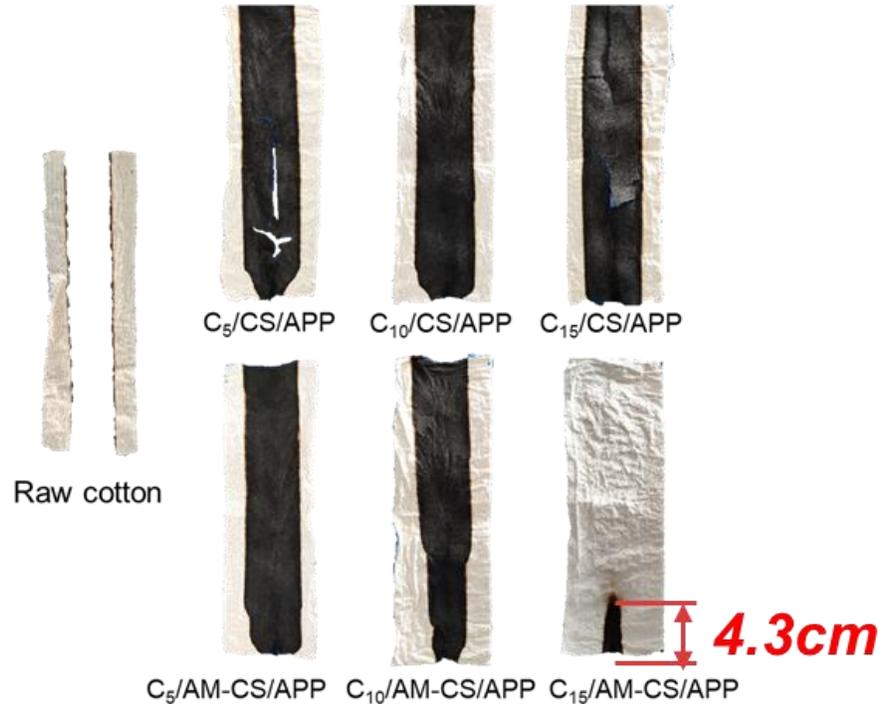


# 低毒、低刺激

聚磷酸铵/壳聚糖/对氨基  
苯磺酸改性三聚氰胺 → 棉

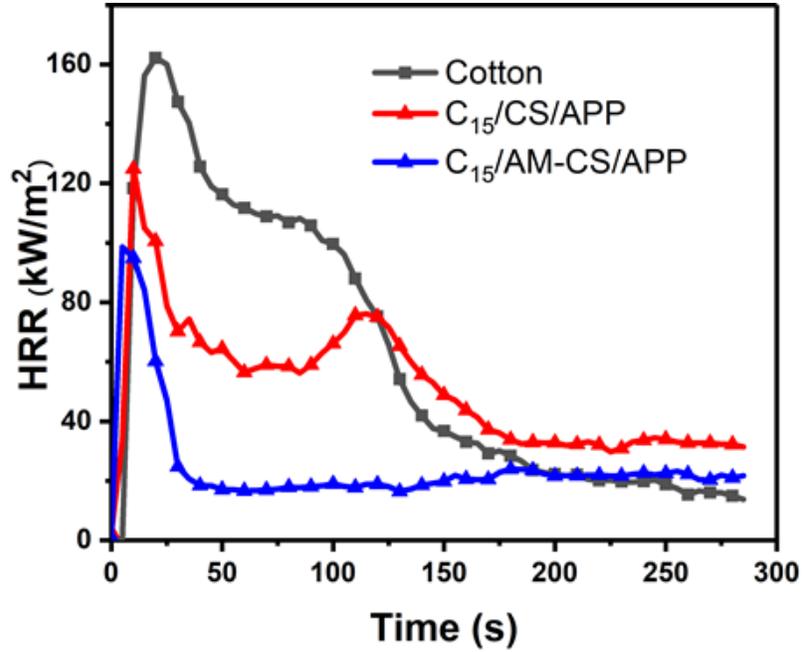


棉织物样品的LOI值和垂直燃烧测试结果

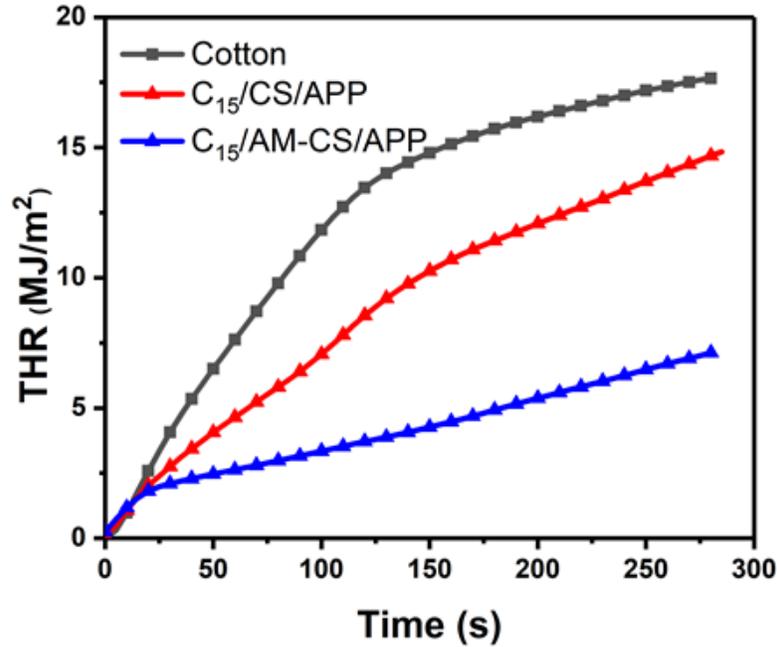


Sample	LOI	Damage length (cm)
Cotton	$18.1 \pm 0.2$	all
C <sub>5</sub> /CS/APP	$24.1 \pm 0.3$	all
C <sub>10</sub> /CS/APP	$25.7 \pm 0.1$	all
C <sub>15</sub> /CS/APP	$26.0 \pm 0.2$	all
C <sub>5</sub> /AM-CS/APP	$25.6 \pm 0.5$	all
C <sub>10</sub> /AM-CS/APP	$27.8 \pm 0.5$	all
C <sub>15</sub> /AM-CS/APP	$31.5 \pm 0.5$	4.3

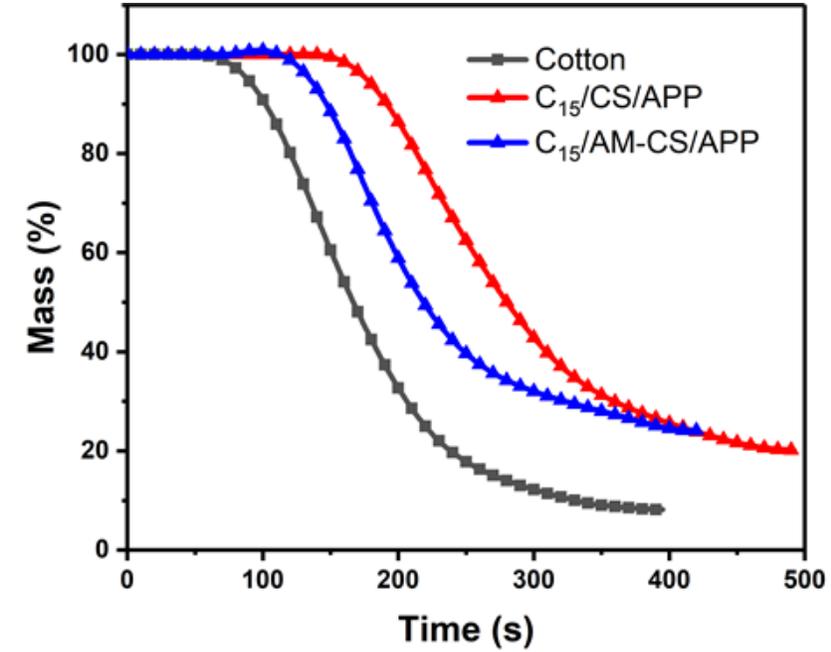
## 聚磷酸铵/壳聚糖/对氨基苯磺酸改性三聚氰胺 → 棉



pHRR 39.2% ↓

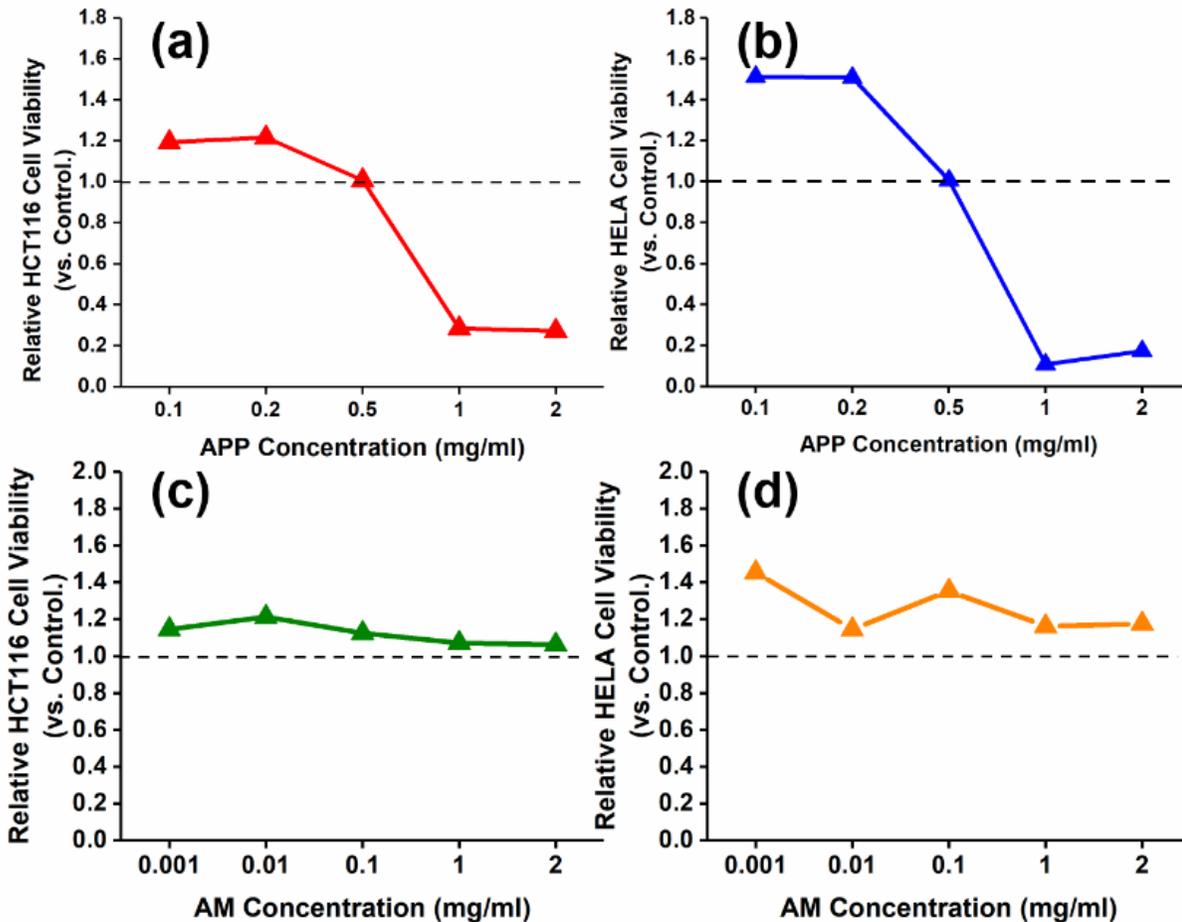


THR 59.9% ↓



Mass 16.0% ↑

## 聚磷酸铵/壳聚糖/对氨基苯磺酸改性三聚氰胺 → 棉

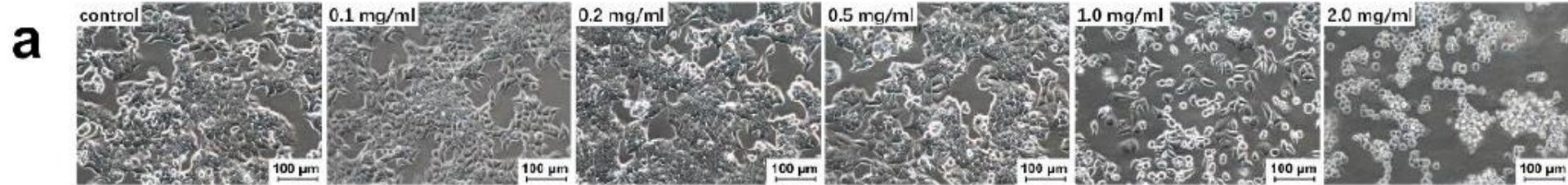


- 细胞增殖能力表现出随 APP 浓度的增加而降低的趋势，具有剂量依赖性。
- 在 AM 中，两种细胞均表现出高于对照组的增殖能力
- 当 APP 与 AM 浓度均为 1 mg/mL 时，APP 抑制细胞的正常增殖，AM 仍保持相对稳定的细胞活力。

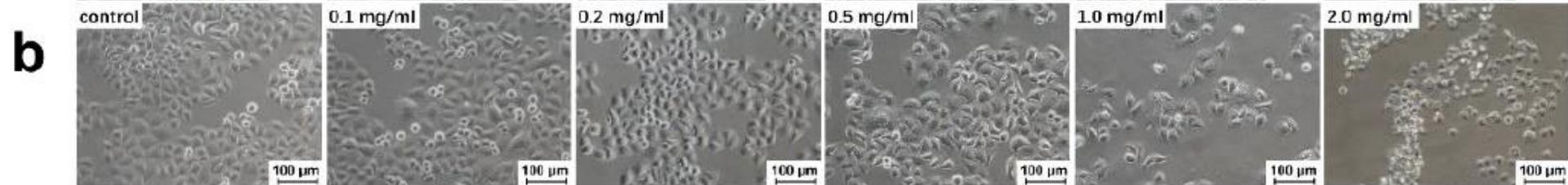
不同浓度的 APP (a, b)和 AM (c, d)对人结肠癌细胞(HCT116)和海拉细胞(Hela) 的增殖能力影响

## 聚磷酸铵/壳聚糖/对氨基苯磺酸改性三聚氰胺 → 棉

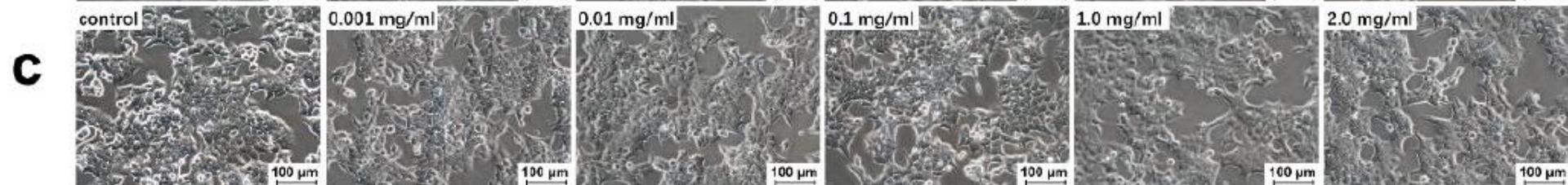
用APP处理HCT116细胞



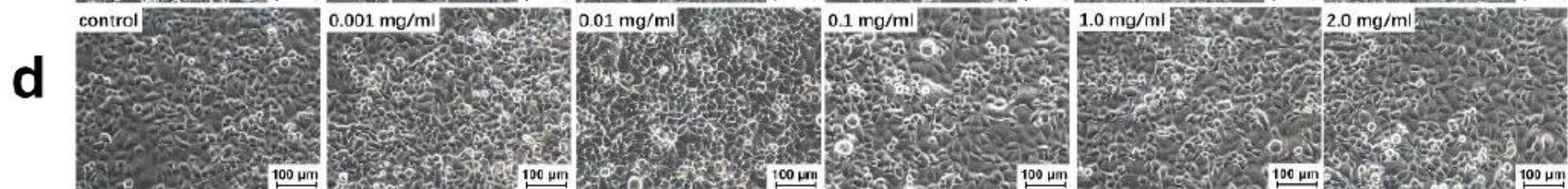
用APP处理HeLa细胞



用AM处理HCT116细胞



用AM处理HeLa细胞



**AM 比 APP 具有更低的细胞毒性，安全浓度范围更广**

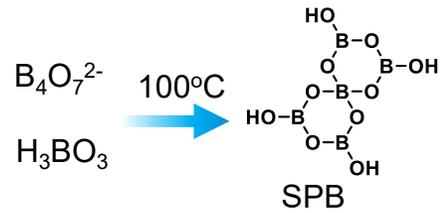
02

**环境友好**

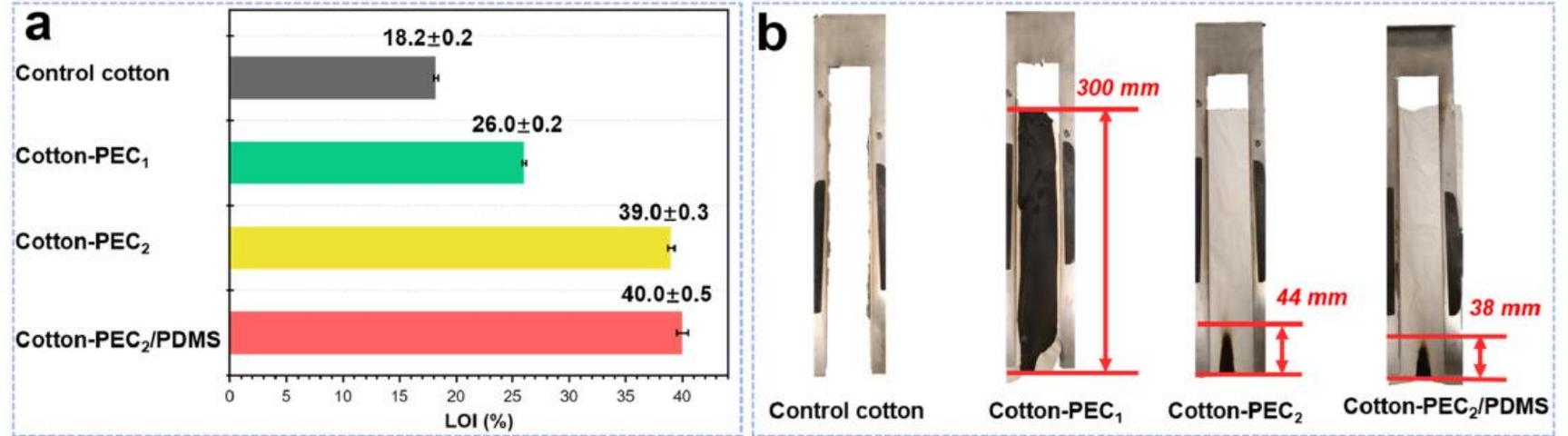
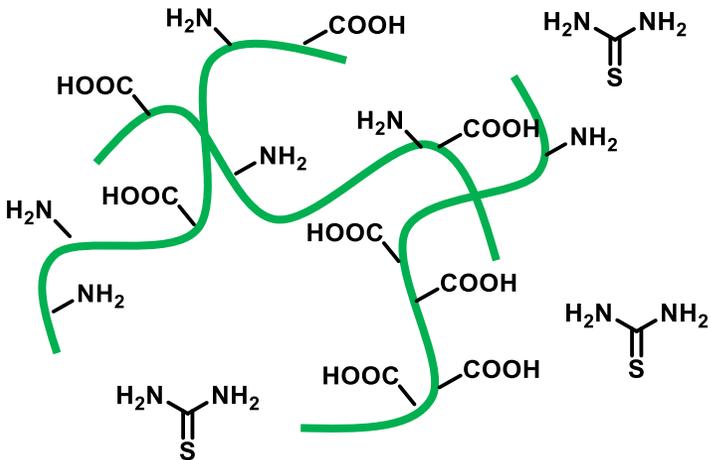


## 无磷体系 → 棉/PA66

## 壳聚糖/聚硼酸钠 (SPB)



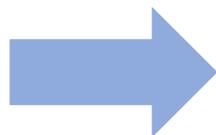
## 大豆蛋白/硫脲



NO.	SPI (wt%)	Thiourea (wt%)	Add on (wt%)	LOI (%)	Vertical burning test		
					Damaged length (cm)	After flame time (s)	Dripping/drops
Control	0	0	0	20.5±0.2	15.0±0.5	122.4	lots
1	0	10	8.1	21.6±0.3	13.5±0.4	20	one
2	3	10	8.5	23.4±0.2	4.1±0.5	0	none
3	4	10	8.6	24.0±0.3	5.0±0.4	0	none
4	5	10	9.1	25.5±0.2	4.1±0.3	0	none
5	6	10	9.5	25.1±0.3	4.3±0.6	0	none
6	7	10	9.4	25.0±0.4	4.5±0.5	0	none

环境友好

火安全材料研究中心  
CENTER FOR FIRE SAFETY MATERIALS

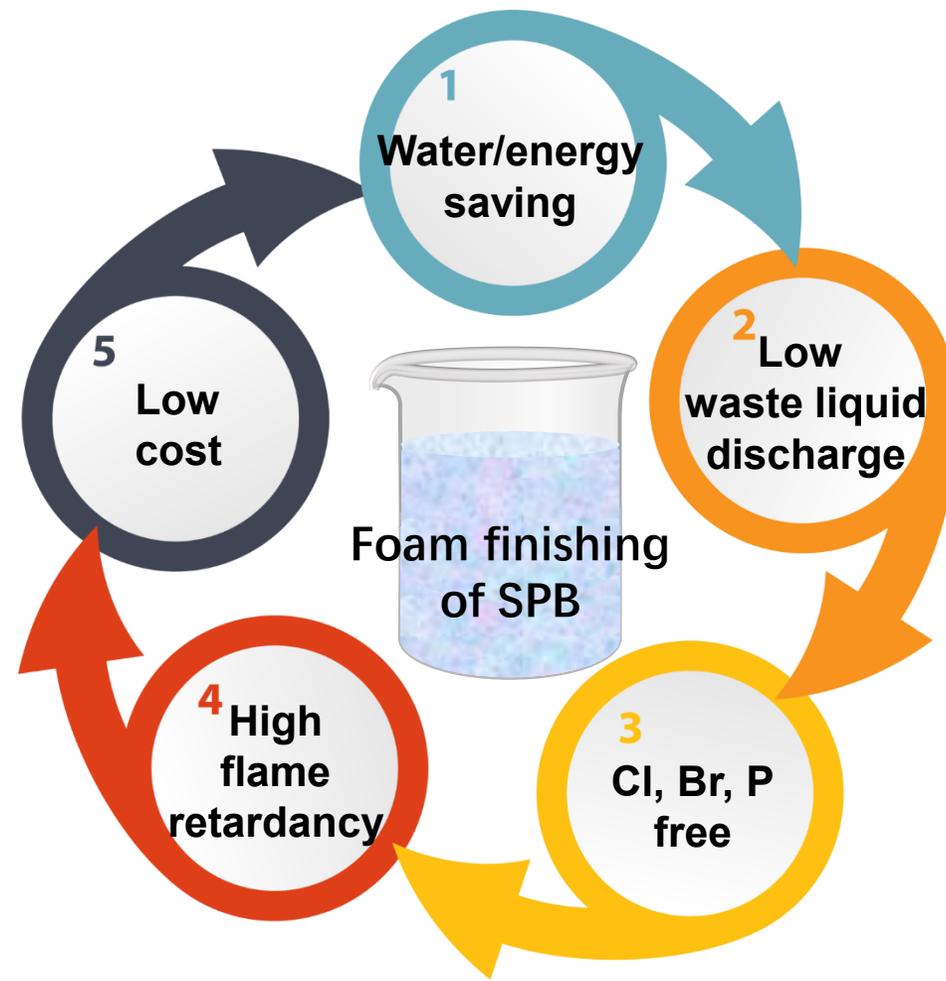
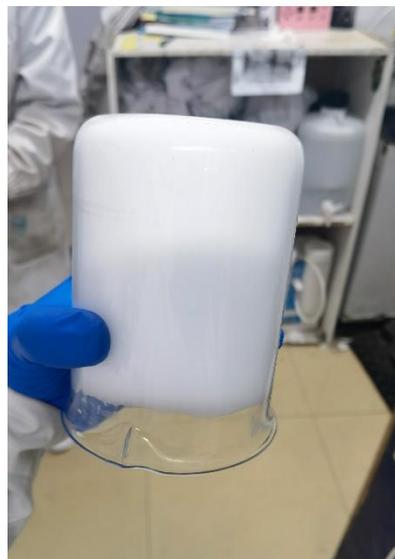
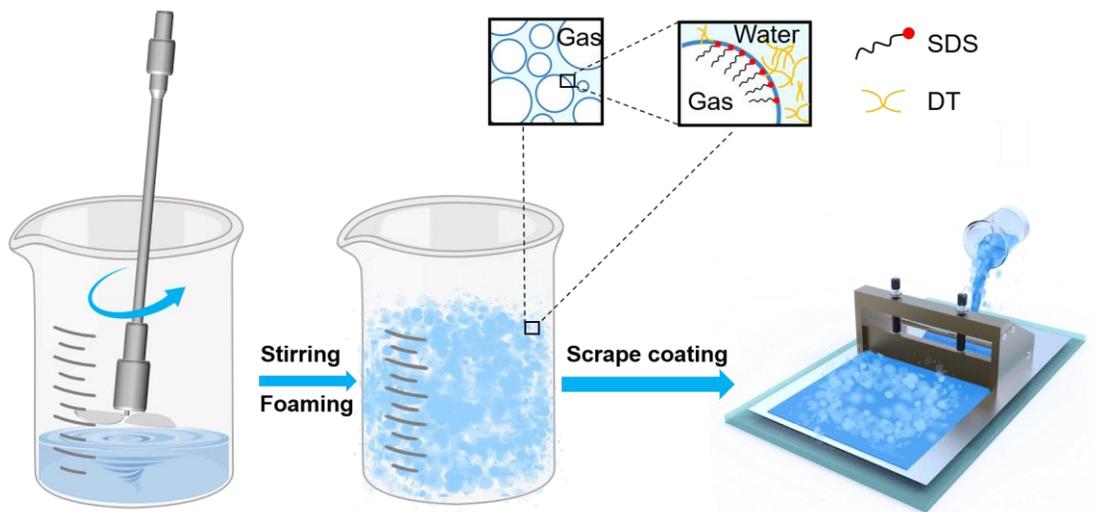


**无需水洗**  
随时随地享受健康  
不惧二次入口危机

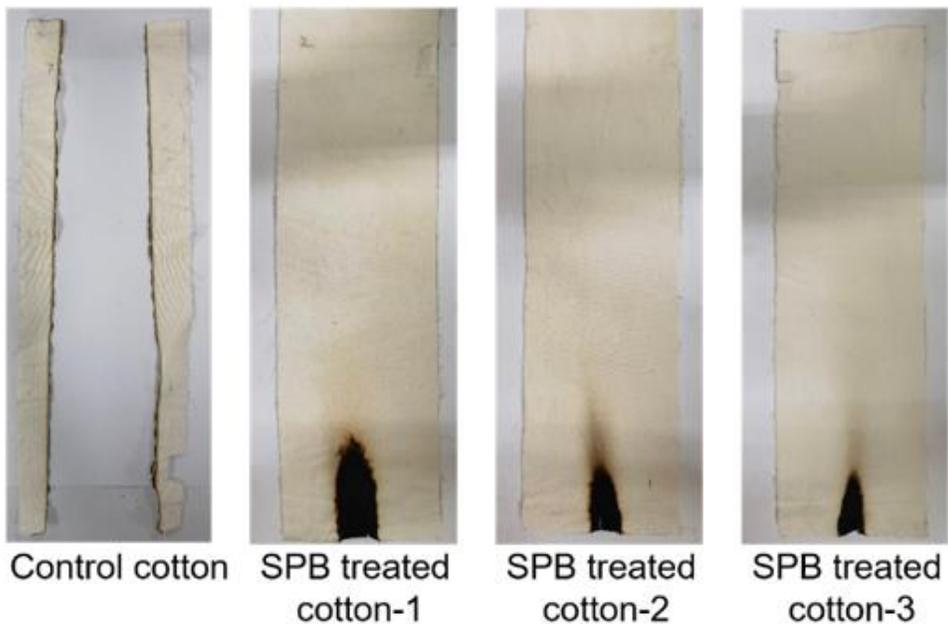


速干不粘手 小手更清爽

## 无水体系



## 无水体系→棉织物

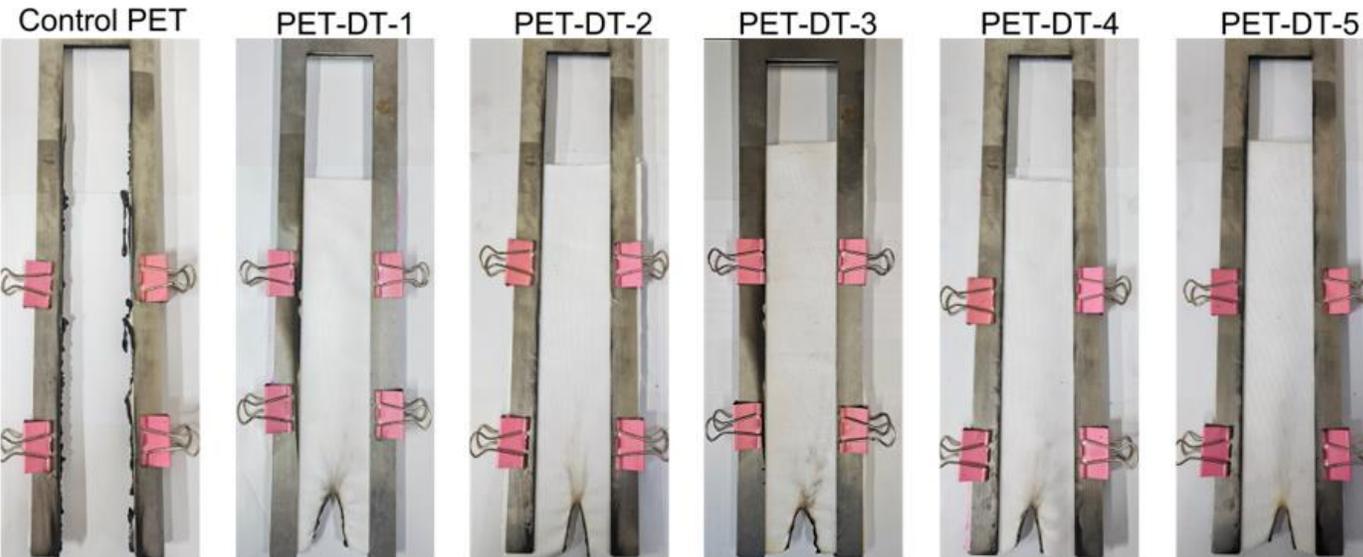


Sample	WG (%)	LOI (%)	After-flame time (s)	After-glow time (s)	Damaged length (mm)
Control cotton	-	18.5±0.1	13	15	300
SPB treated cotton-1	6.7±0.5	32.6±0.2	0	0	57
SPB treated cotton-2	11.4±0.8	43.7±0.2	0	0	35
SPB treated cotton-3	16.7±1.0	46.7±0.3	0	0	33

## 无水体系 → 涤纶



无溶剂合成  
节水整理



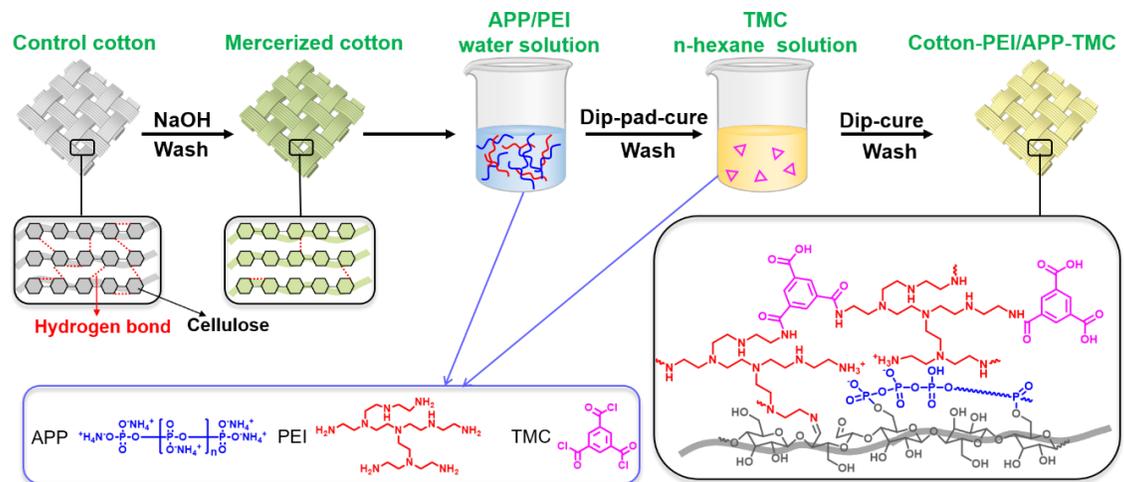
Sample	WGR (wt%)	LOI (%)	T <sub>after flame</sub> (s)	Damaged length (mm)	Dripping
Control PET	-	18.9±0.2	100	300	Yes
PET-DT-1	2.7±0.3	21.5±0.2	0	40	No
PET-DT-2	5.2±0.2	22.7±0.2	0	37	No
PET-DT-3	10.3±0.5	24.3±0.3	0	32	No
PET-DT-4	14.7±0.5	26.5±0.2	0	30	No
PET-DT-5	19.4±0.7	27.1±0.2	0	28	No

03

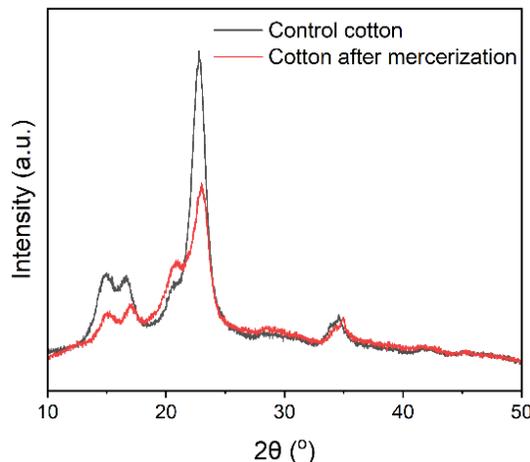
**耐久  
耐水洗**



## Cotton-PEI/APP-TMC的制备



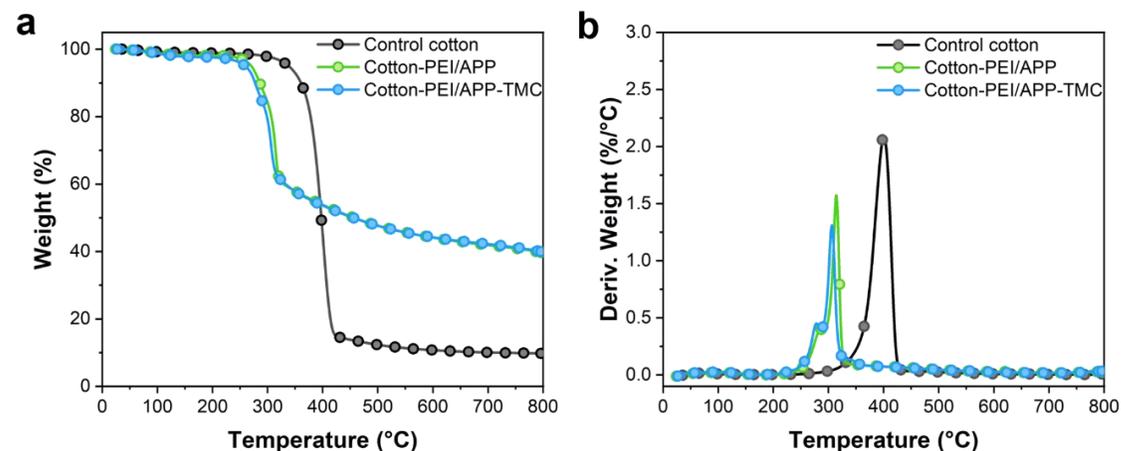
- 丝光处理后，棉织物的相对结晶度从 Control cotton 的 69.0% 降低到 37.2%



- 通过聚磷酸铵 (APP) 和聚乙烯亚胺 (PEI) 的共价键合，再进行PEI与三苯磺酰氯 (TMC) 的界面聚合，制备超耐久的阻燃棉织物

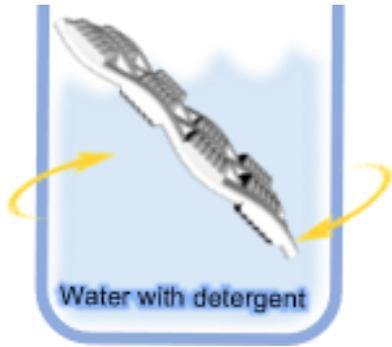
## 阻燃性能

样品	WG (%)	LOI (%)	续燃时间 (s)	阴燃时间 (s)	损毁长度 (mm)
Control cotton	/	18.2 ± 0.2	13	64	300
Cotton-PEI/APP	19.0 ± 1.5	42.2 ± 0.2	0	0	39
Cotton-PEI/APP-TMC	19.9 ± 1.7	42.0 ± 0.4	0	0	38



- Cotton-PEI/APP-TMC样品的LOI值达到42%，损毁长度仅为38 mm
- Cotton-PEI/APP-TMC样品拥有最低的热释放
- Cotton-PEI/APP-TMC样品分解温度提前，残碳量明显提升

## 耐久性测试

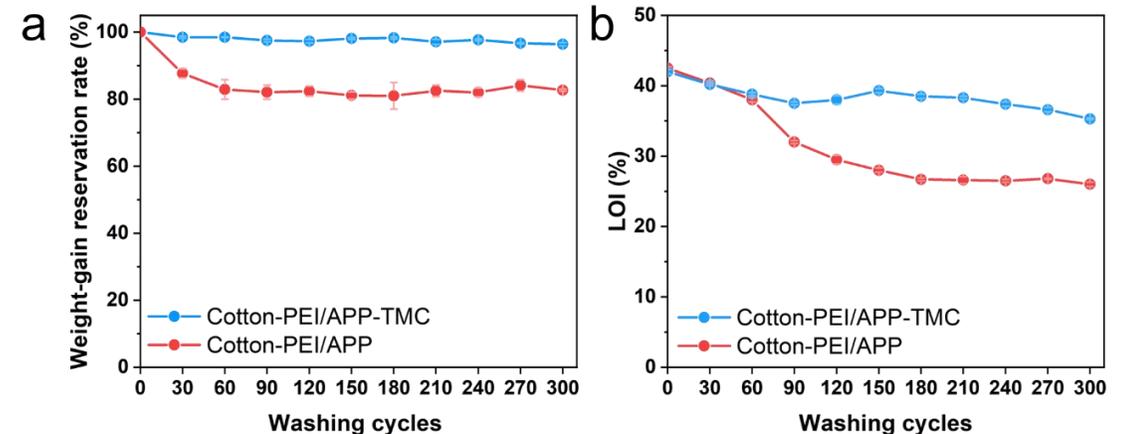
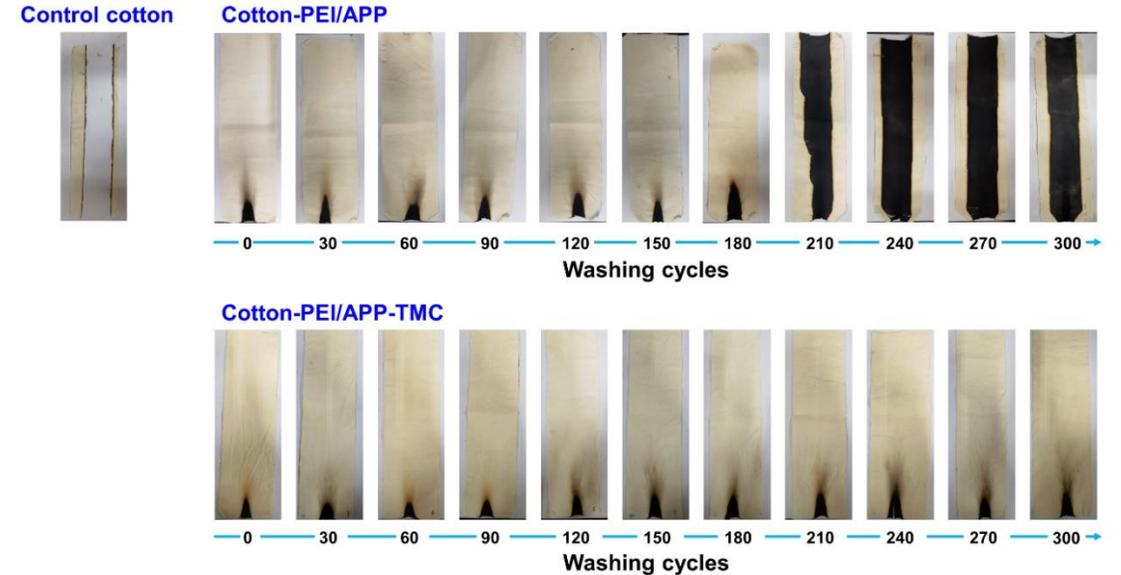


49°C

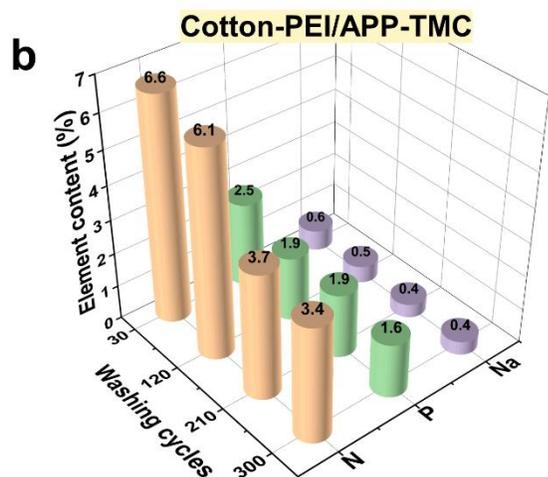
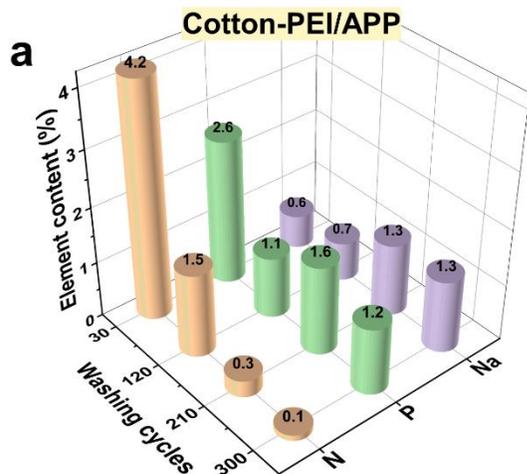
去离子水 & 自来水(含钙、镁离子)

0.15%洗涤剂

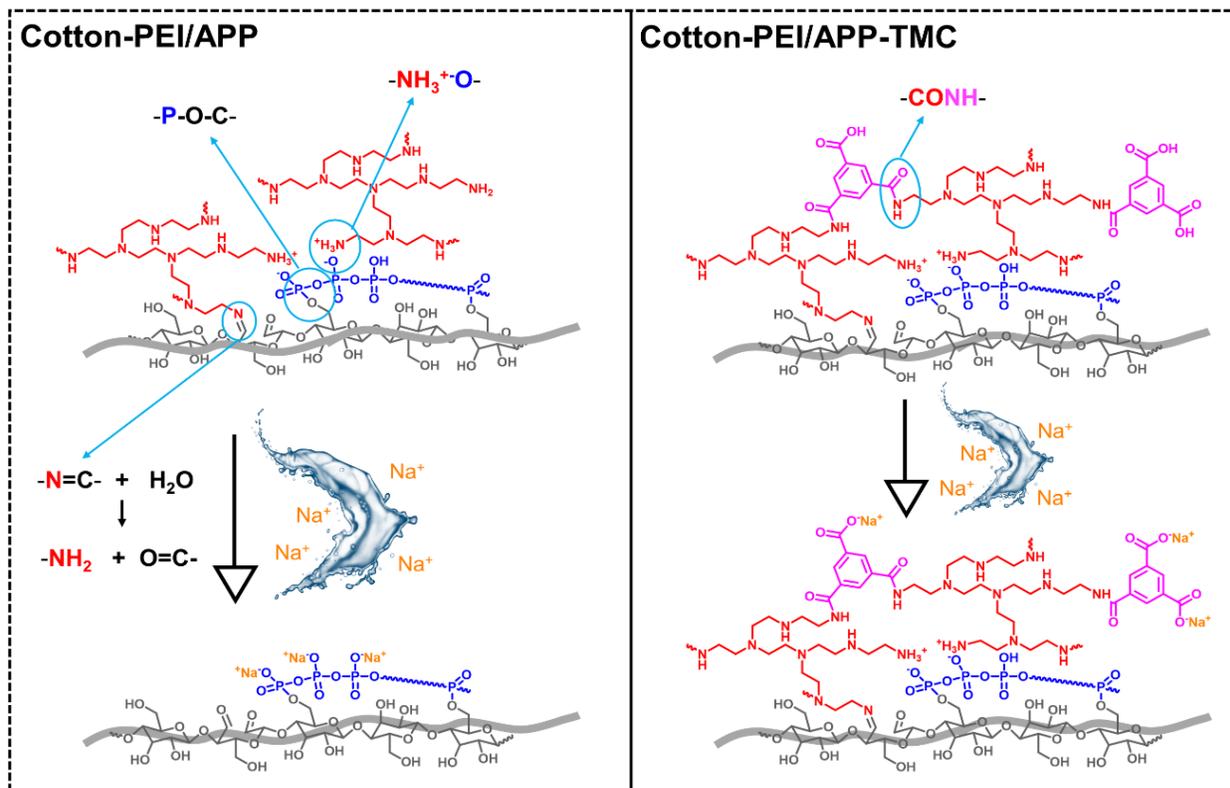
- Cotton-PEI/APP-TMC样品的在经过300次水洗循环后, 增重和LOI值相比较cotton-PEI/APP样品下降更少
- Cotton-PEI/APP-TMC样品经过300次水洗循环后通过垂直燃烧测试, 损毁长度低



## 元素含量

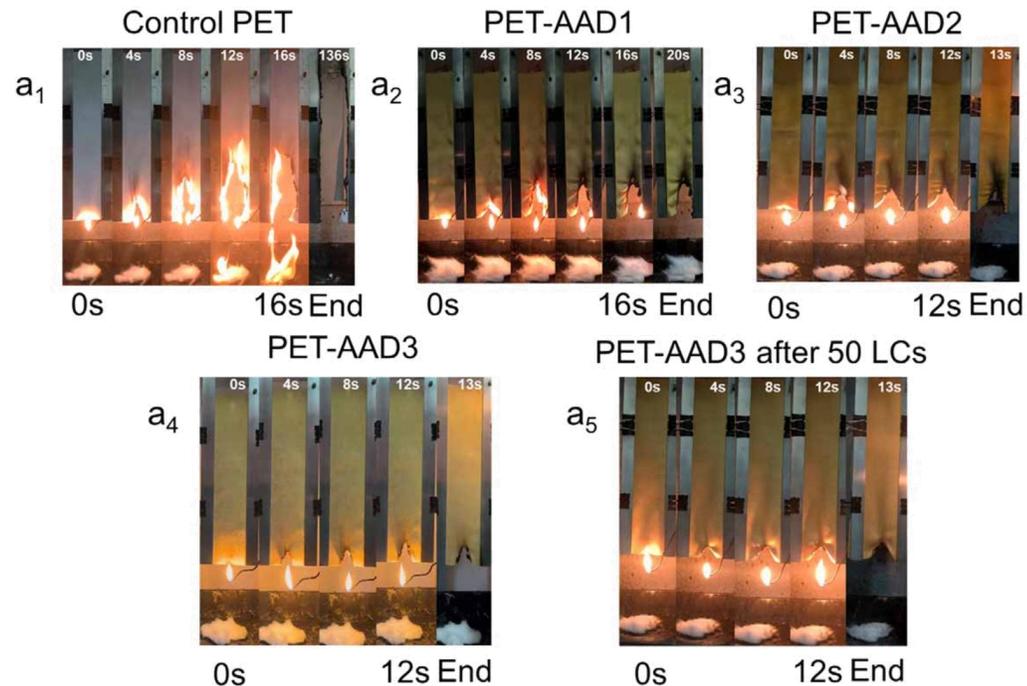
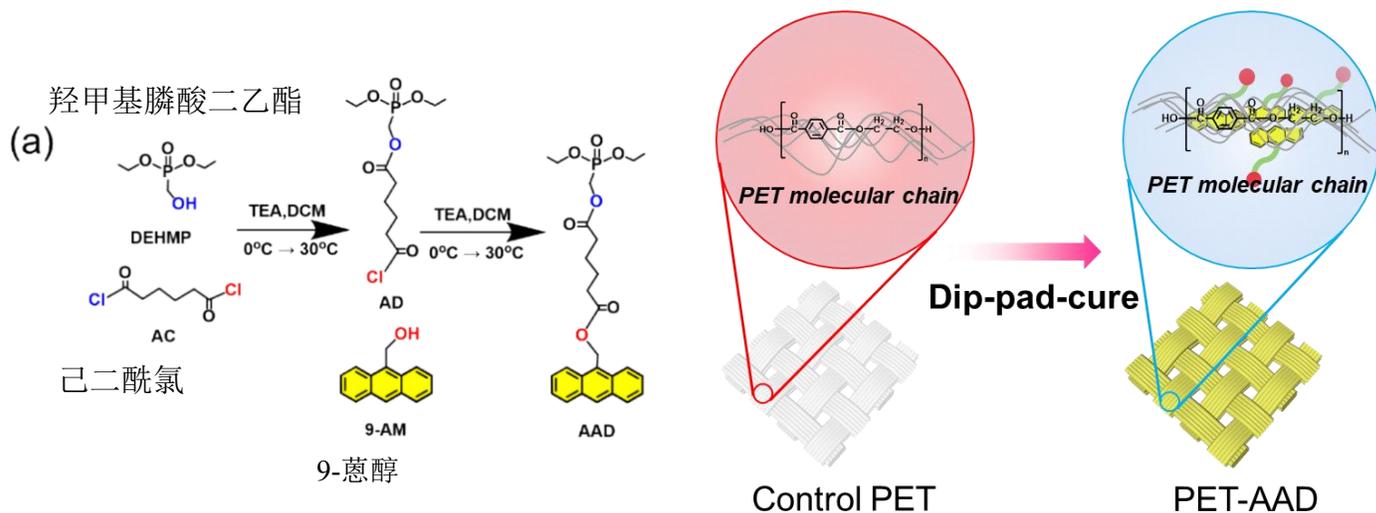


## 耐久阻燃机理

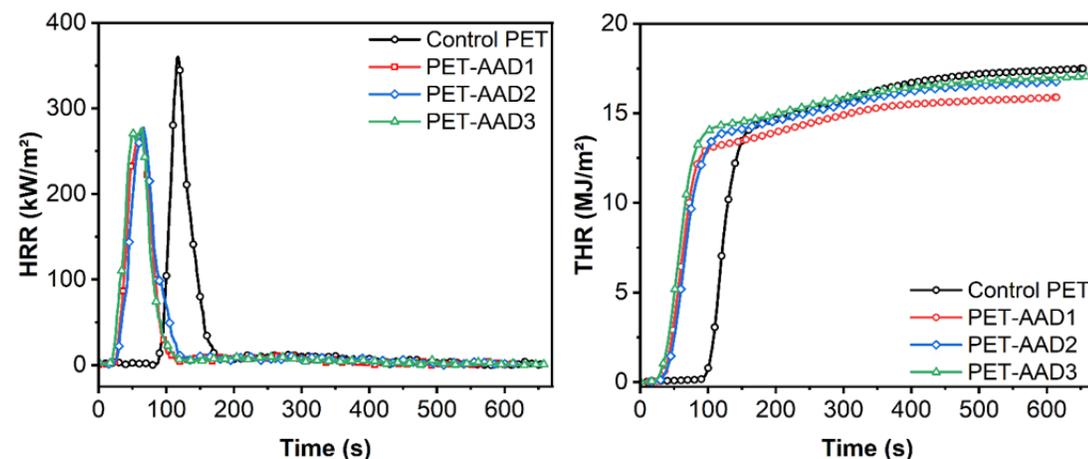


- 对于Cotton-PEI/APP-TMC样品，TMC与PEI的界面聚合产物降低了整个涂层的水溶性，提高了PEI的稳定性
- TMC与PEI的界面聚合产物作为保护层，减少了水中钠离子与磷酸根基团的结合，提高了样品的阻燃耐久性能

## 耐久阻燃及回收体系 → 涤纶



Samples	WG (%)	LOI (%)	T <sub>a-f</sub> (s)	DL (cm)	Dripping
Control PET	-	19.3±0.2	124±2	30.0	Yes
PET-AAD1	7.9±0.3	21.5±0.3	8±1	7.9	No
PET-AAD2	16.3±0.2	22.6±0.3	0	4.5	No
PET-AAD3	22.7±0.3	23.8±0.4	0	2.9	No
PET-AAD3 after 50 LCs	20.4±0.5	23.3±0.2	0	3.3	No



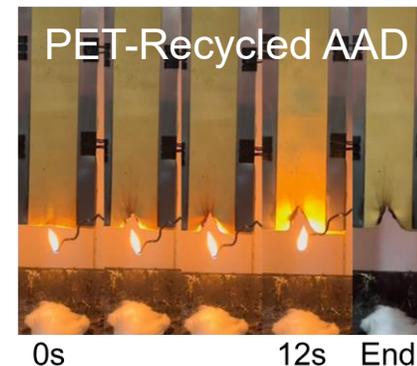
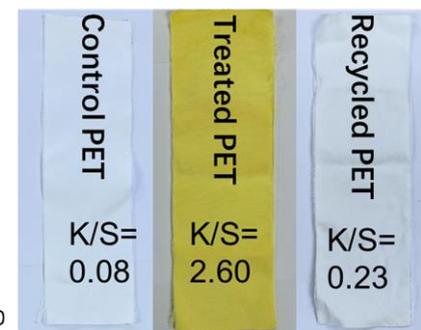
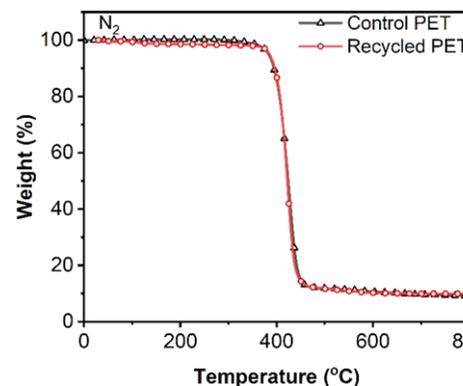
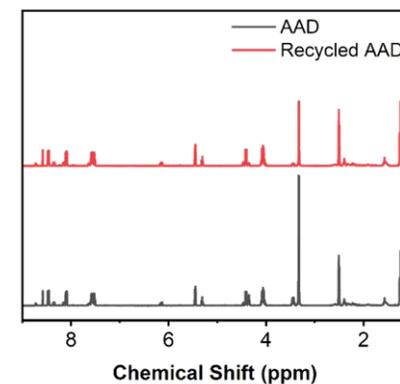
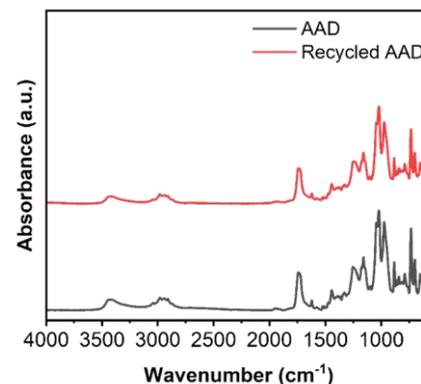
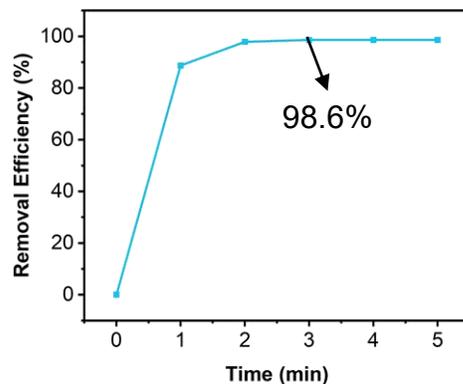
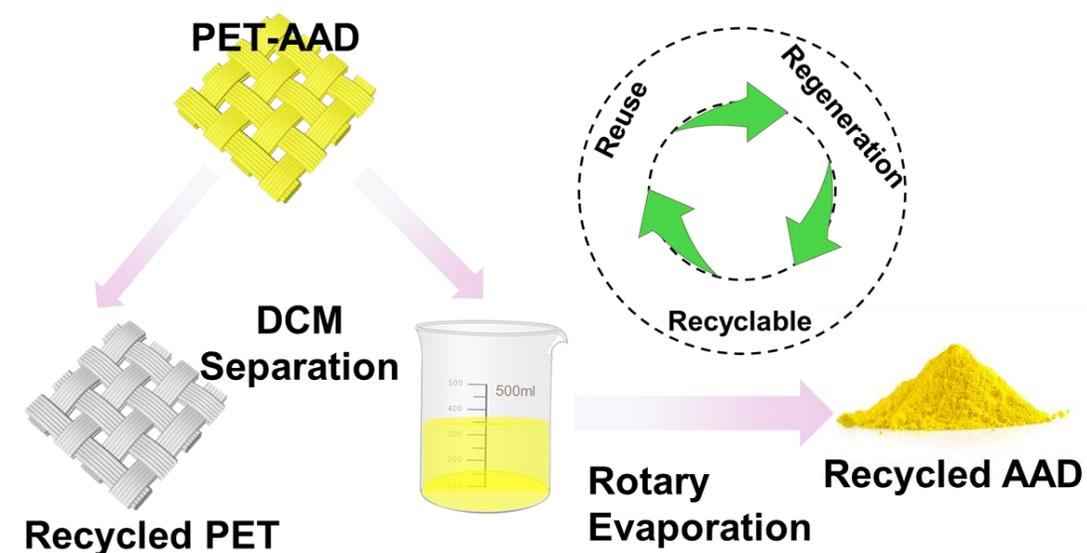
➤ 阻燃剂赋予涤纶织物耐久阻燃性能

Qu YL, Sun J, et al. Chemical Engineering Journal, 500, 2024, 157360.

➤ 阻燃剂有效抑制了涤纶织物燃烧过程中的热释放

## 耐久阻燃及回收体系 → 涤纶

### ◆ 可回收重复利用性能



➤ 三分钟脱除效率达**98.6%**

➤ FT-IR和<sup>1</sup>H NMR表明回收前后的阻燃剂**结构一致**

➤ 类似的TG曲线和相似的K/S值表明阻燃剂**回收充分**

➤ 阻燃剂能够**再次**应用于涤纶织物赋予其阻燃性能

04

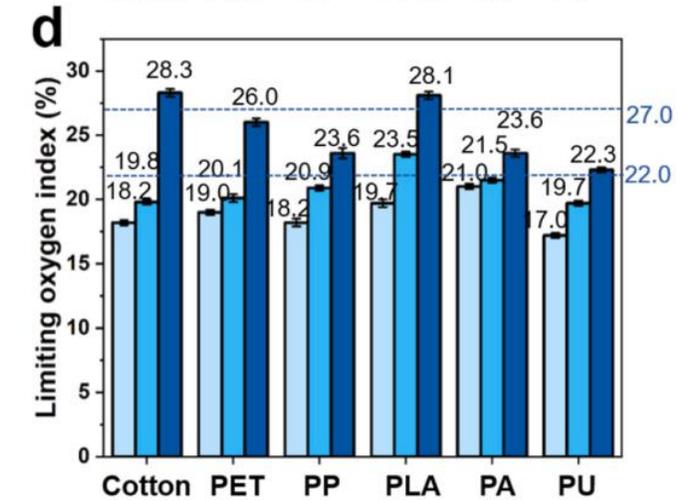
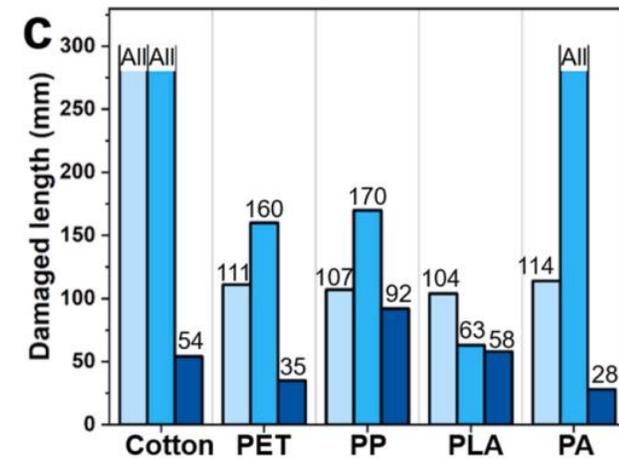
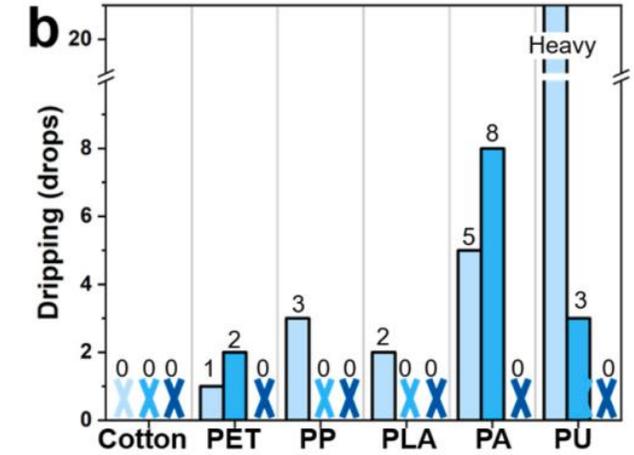
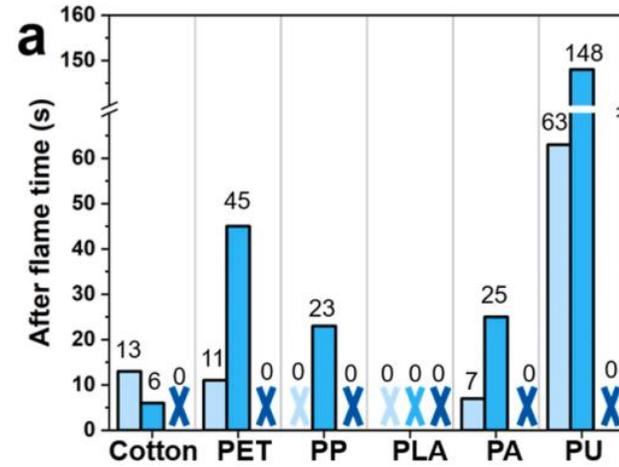
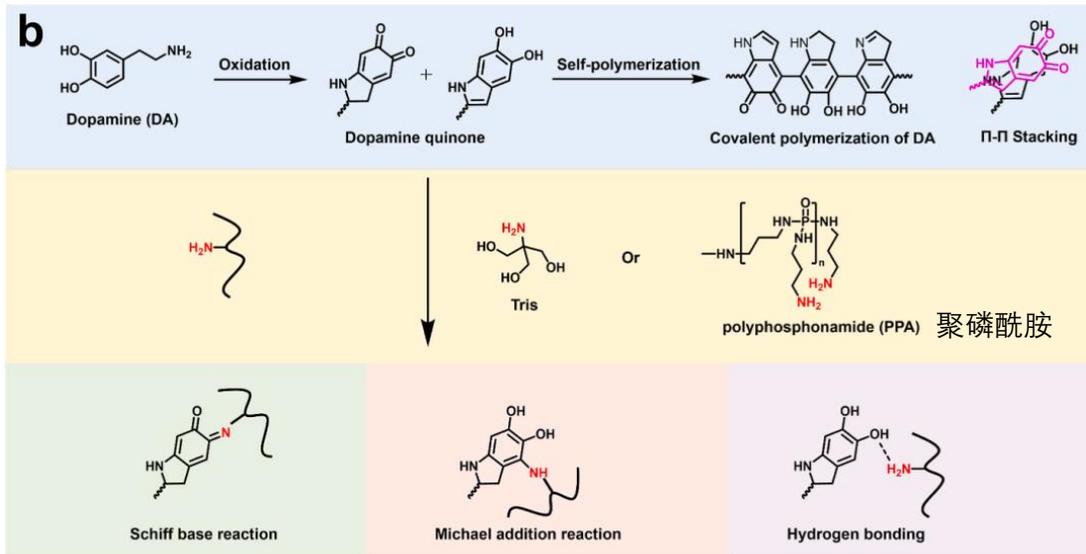
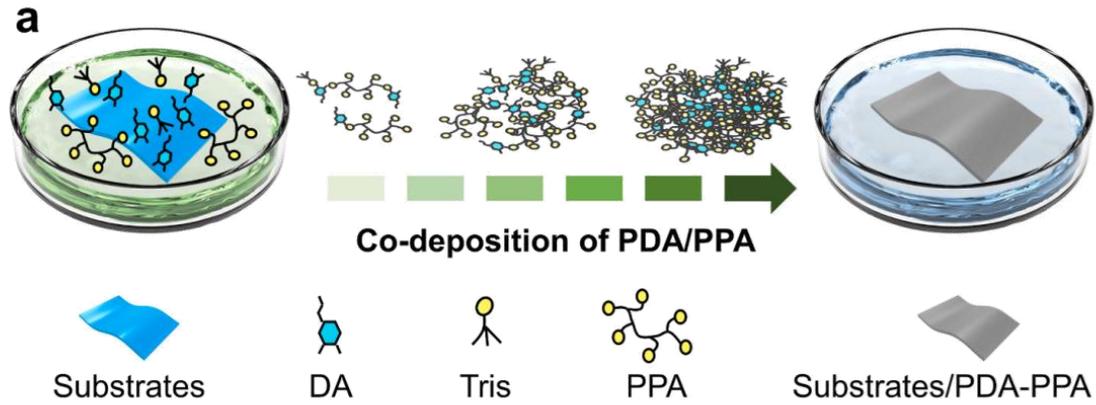
**多基体  
通用**

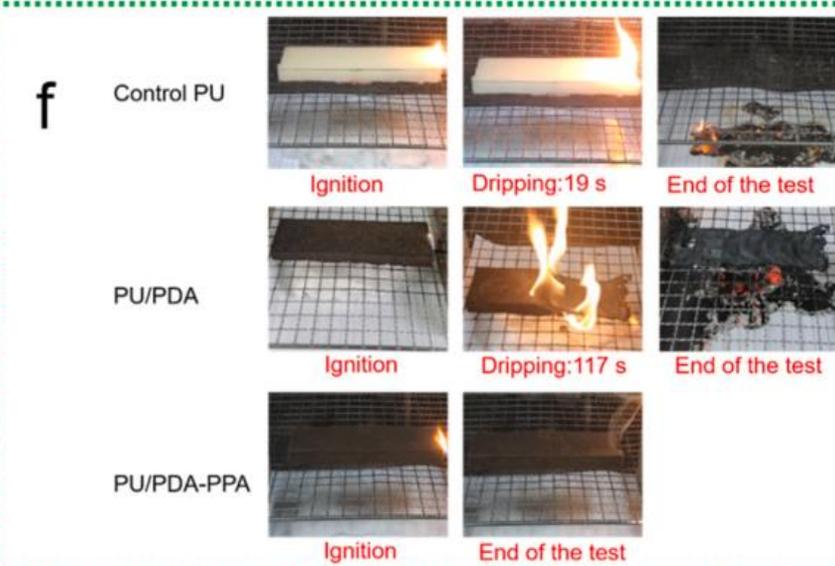
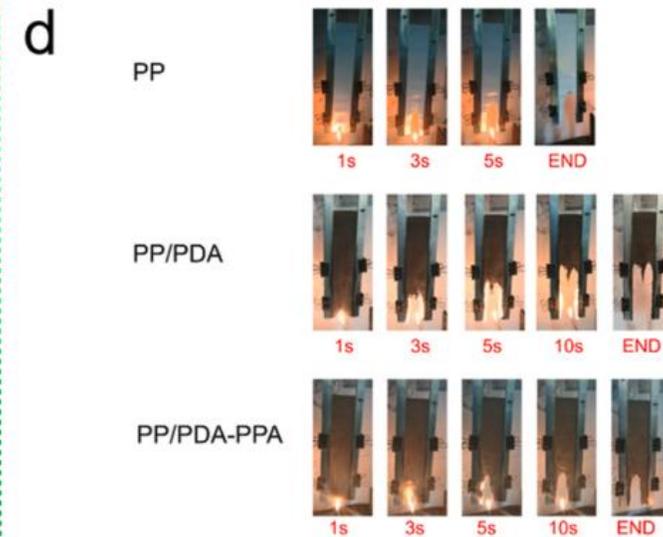
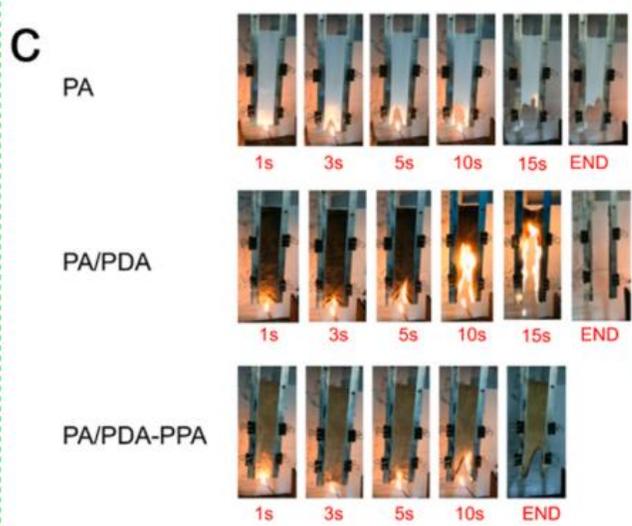
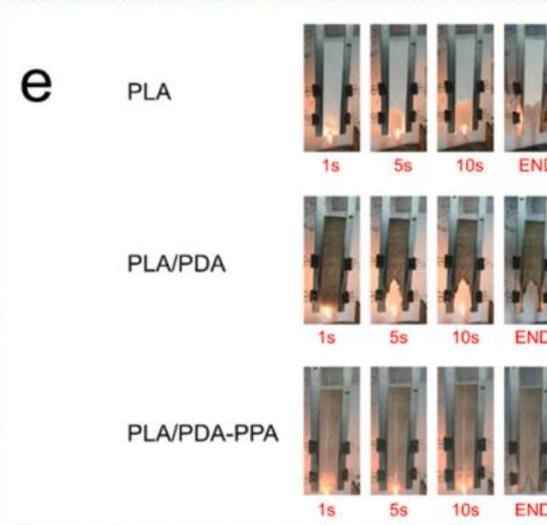
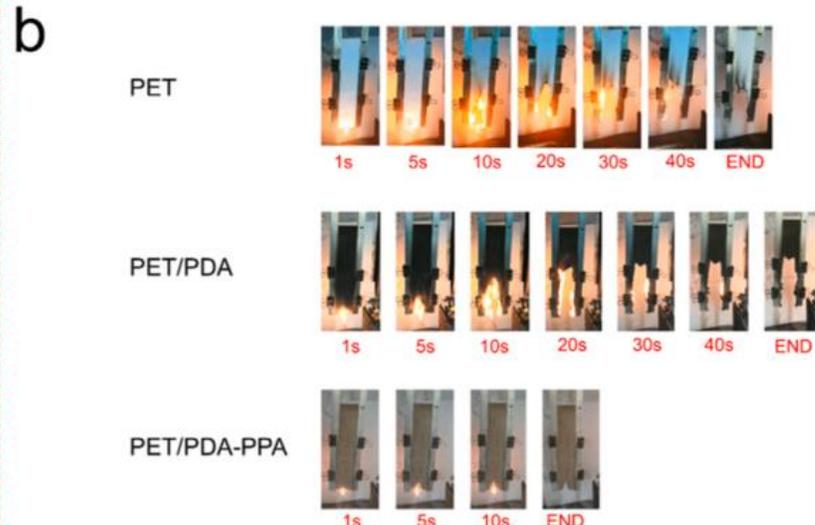
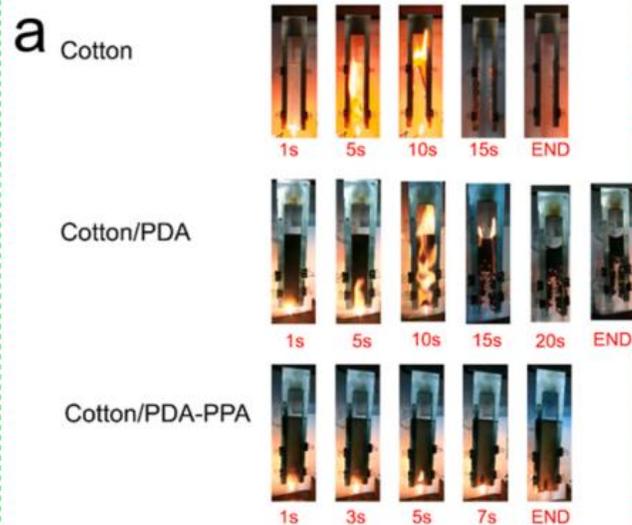
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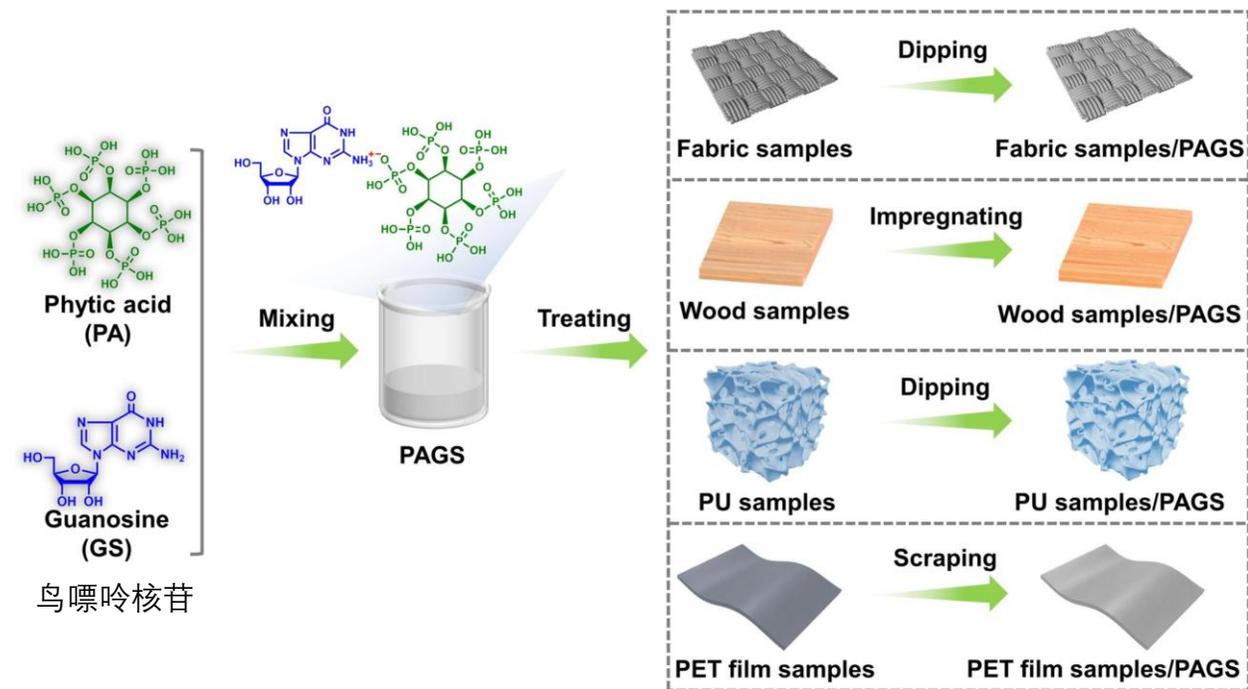


适用于多种  
纺织品基材

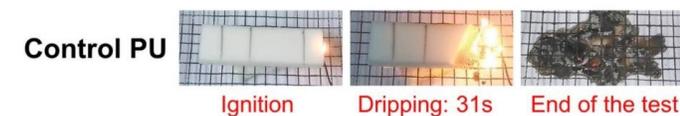
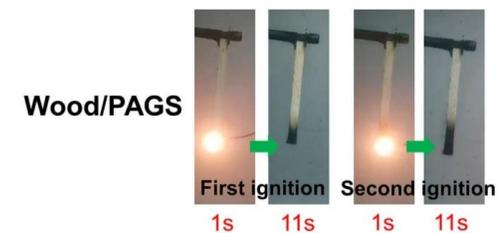
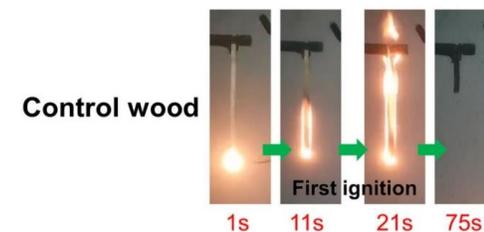
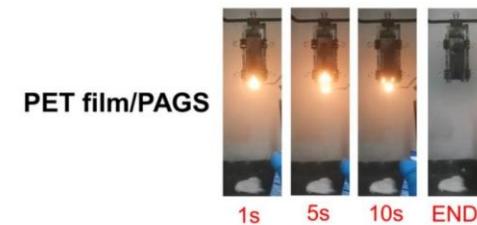
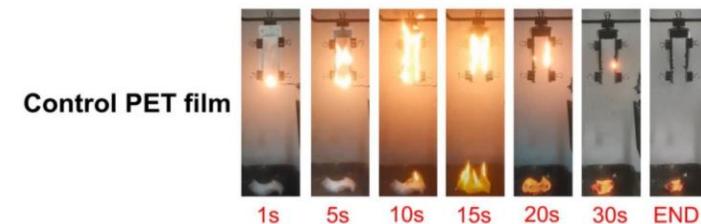
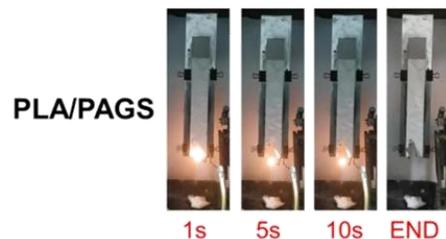
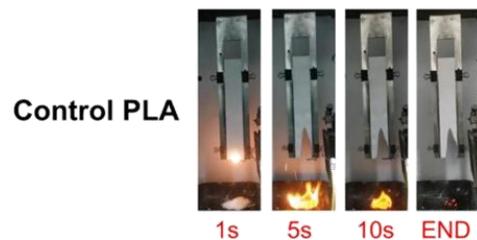
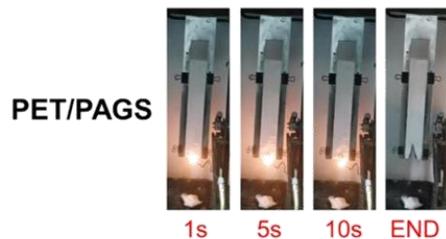
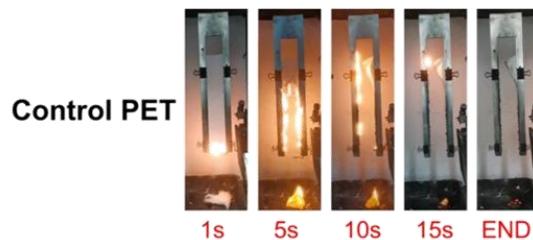
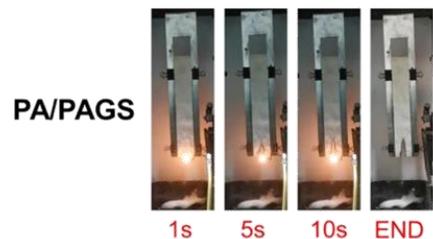
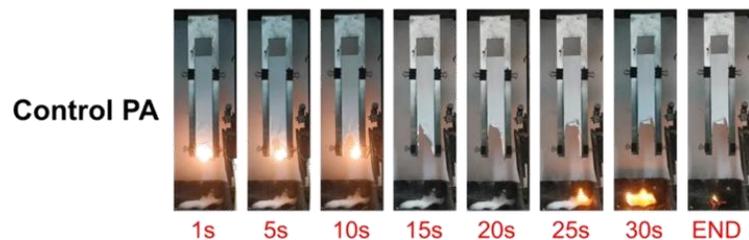
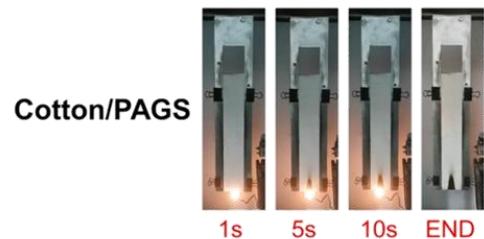
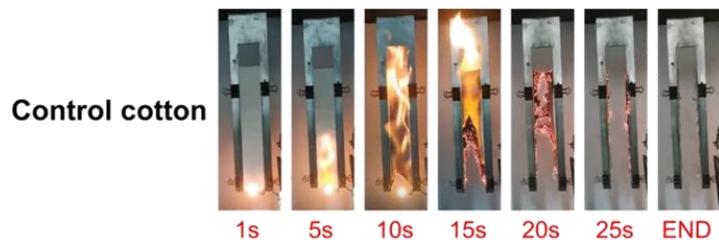
# 多基体通用







Sample	WG (%)	LOI (%)	Vertical or horizontal burning test		
			After-flame time (s)	Damaged length (cm)	Dripping
Control cotton	-	18.3	12	30	-
Cotton/PAGS	15%	28.5	0	3.5	-
Control PET	-	18.9	4	30	Yes
PET/PAGS	20%	28.6	0	3.5	No
Control PA	-	19.2	13	11.5	Yes
PA/PAGS	20%	23.2	0	5.5	No
Control PLA	-	20.1	0	8.5	Yes
PLA/PAGS	20%	28.1	0	5.5	No
Control wood	-	22.8	96	12	-
Wood/PAGS	7%	40.3	0	3.5	-
Control PET film	-	18.5	27	12	Yes
PET film/PAGS	25%	30.0	0	5.5	No
Control PU	-	18.3	42	-	Yes
PU/PAGS	40%	25.3	0	-	No



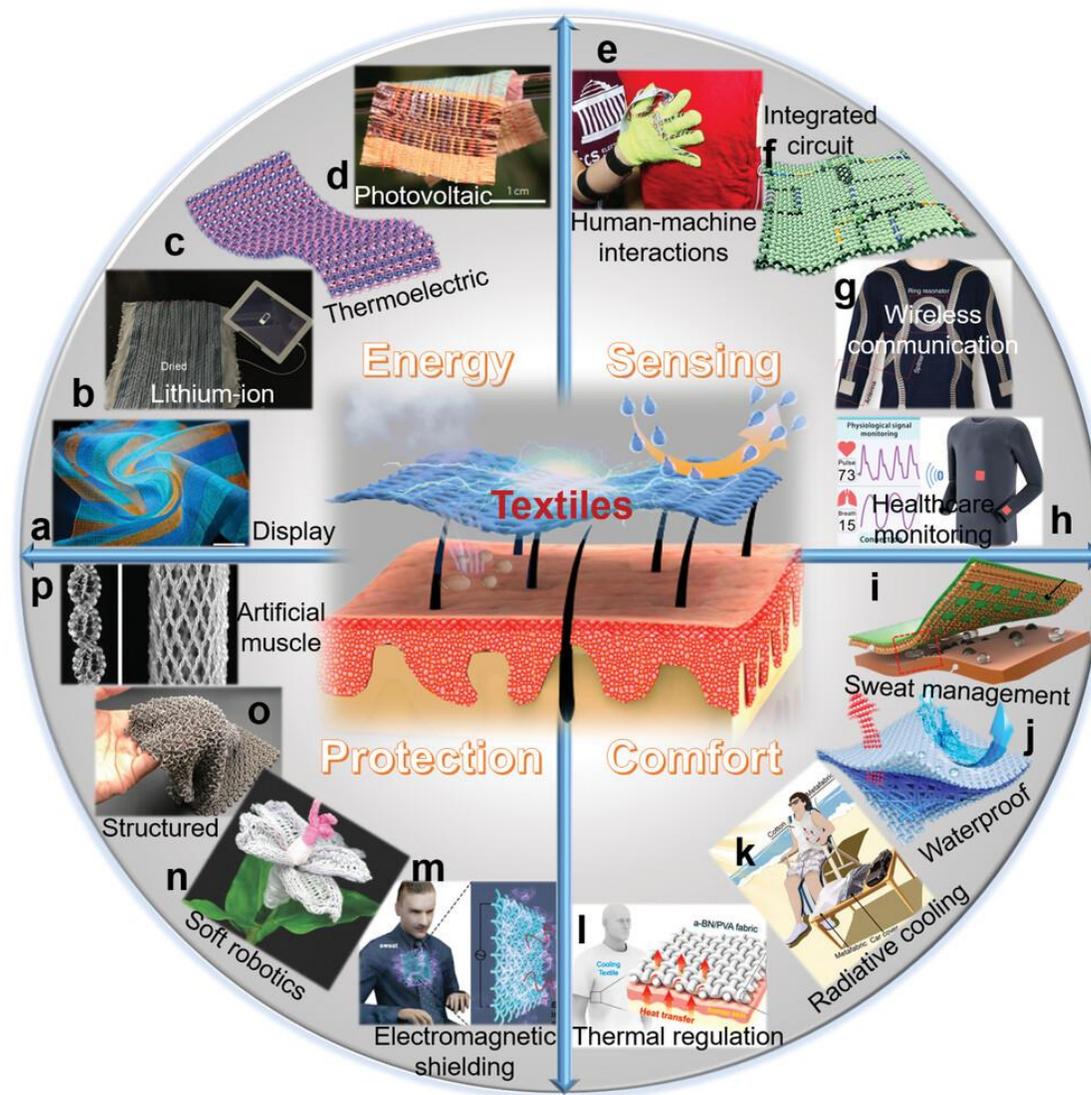
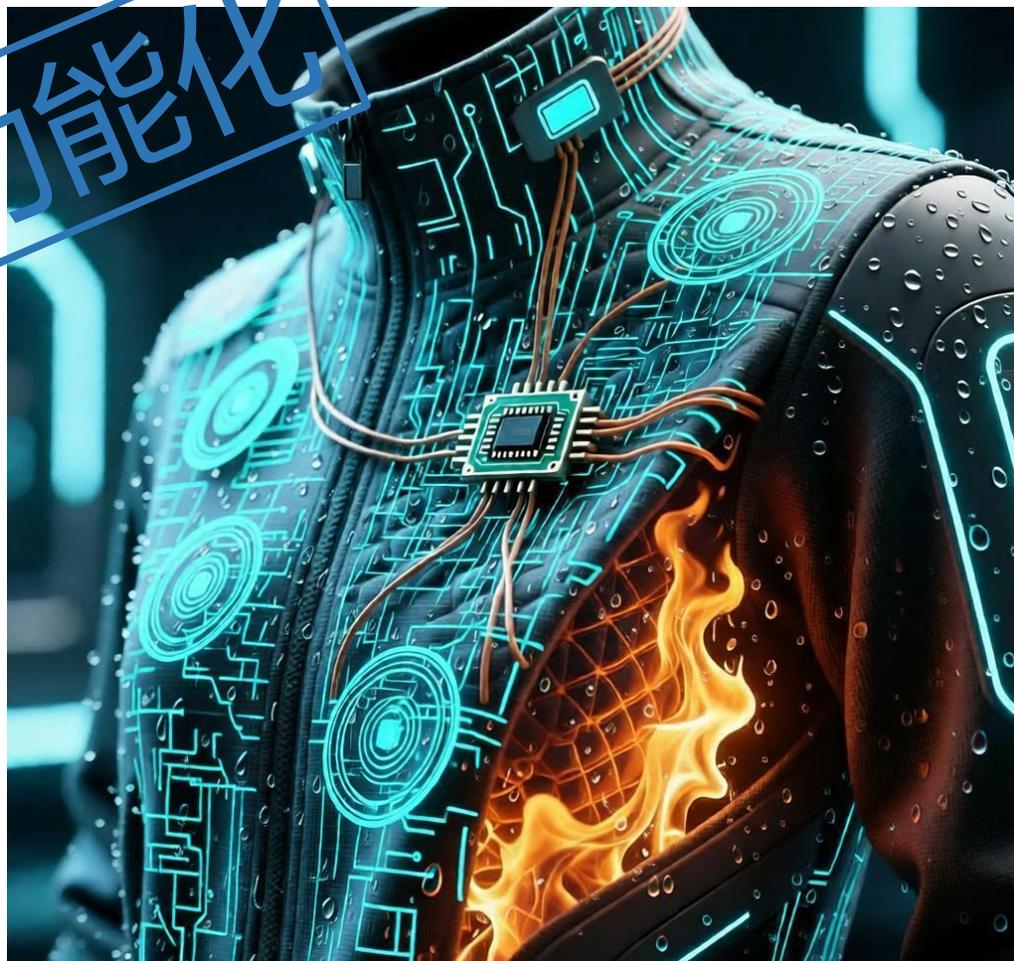
The background features a series of concentric, rounded hexagonal outlines in a light blue color. Scattered around these hexagons are several semi-transparent blue circular dots of varying sizes, creating a modern, geometric aesthetic.

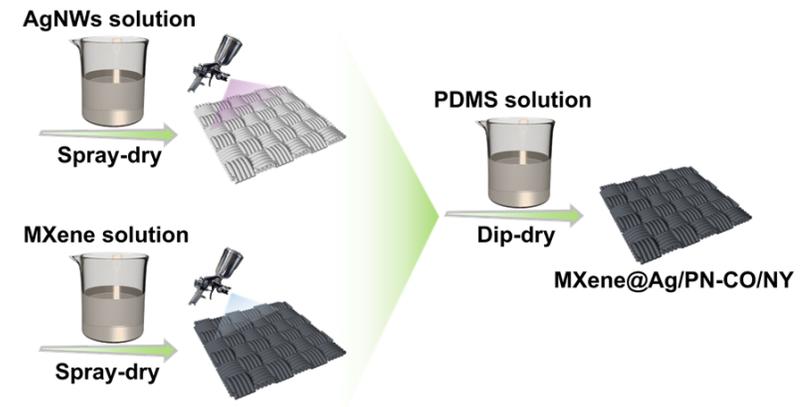
05

**多功能**

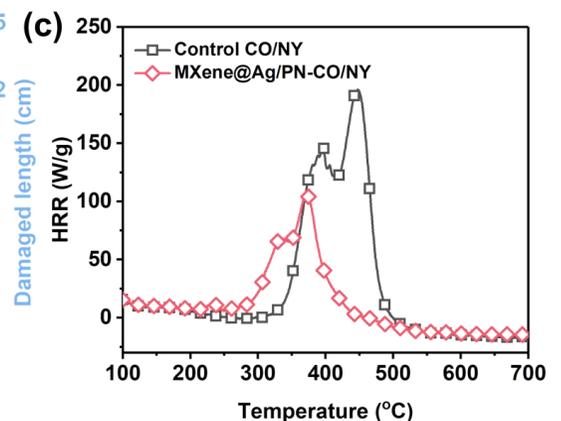
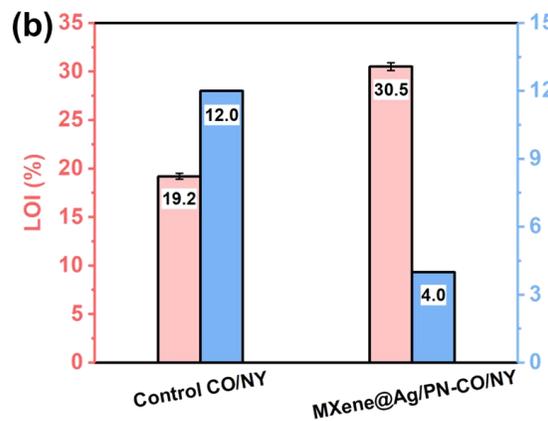
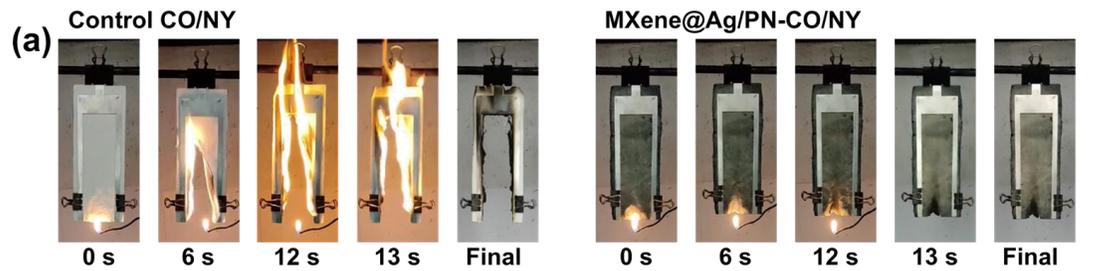
# 多功能

功能化

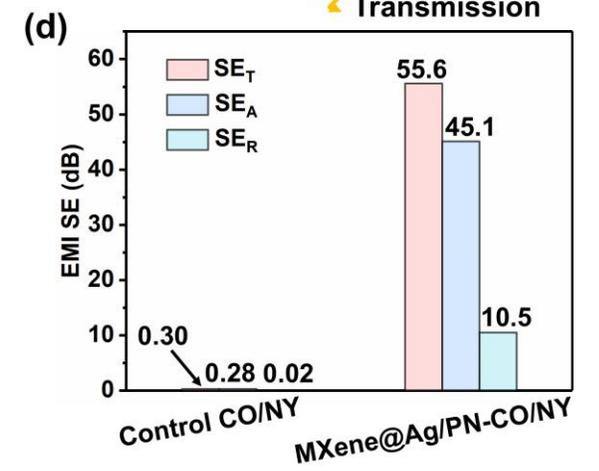
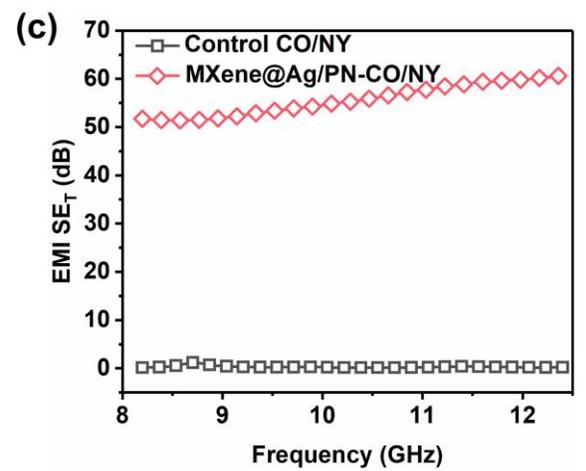
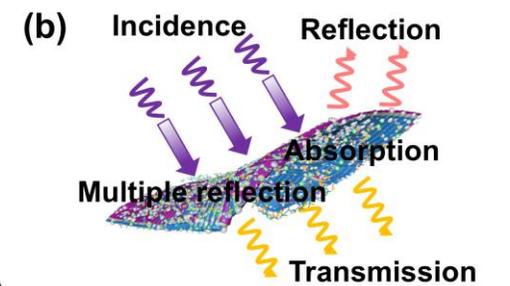
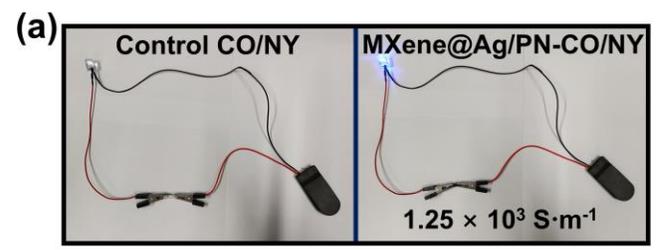




## 阻燃性能测试

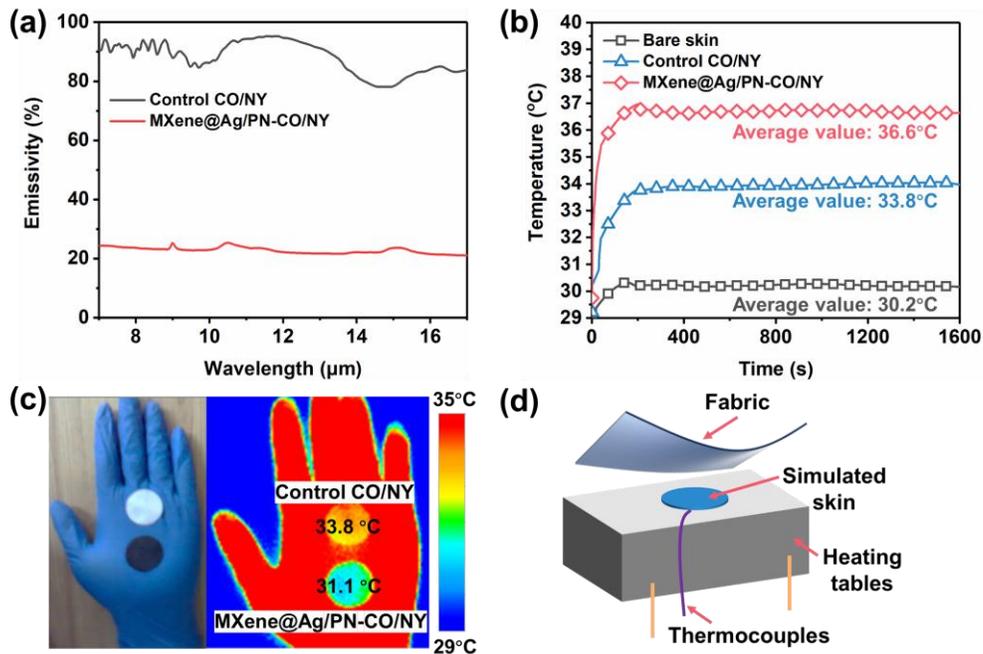


## 导电和电磁屏蔽性能测试

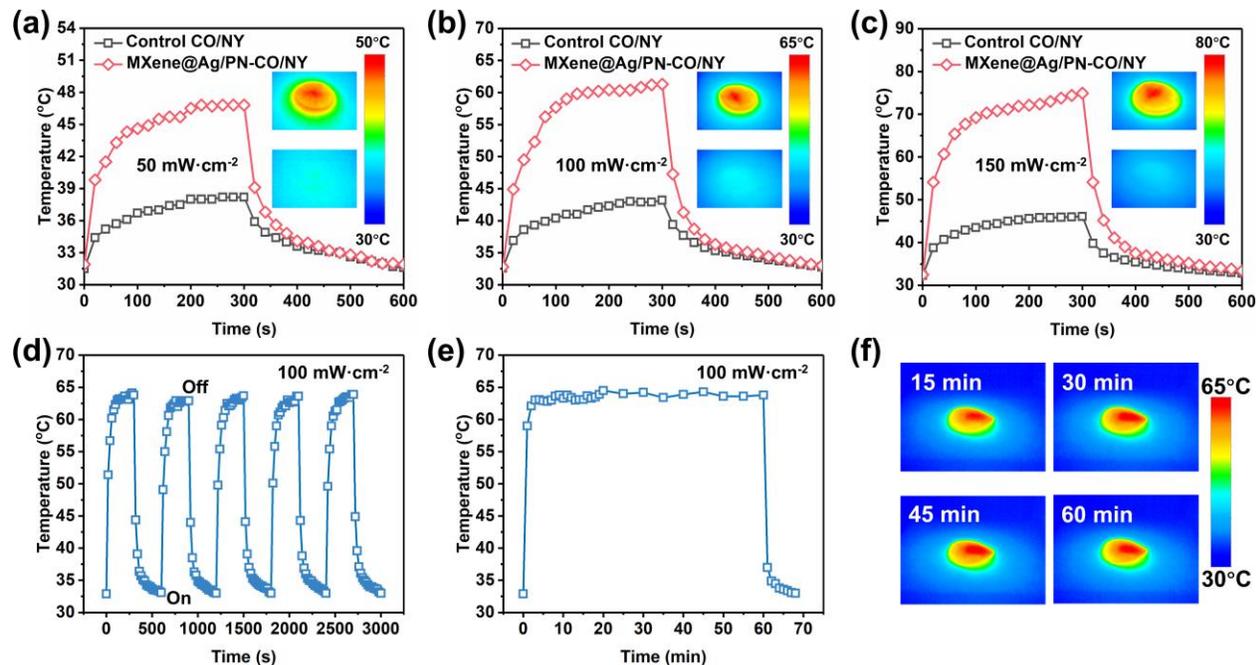


## ● 热管理性能测试

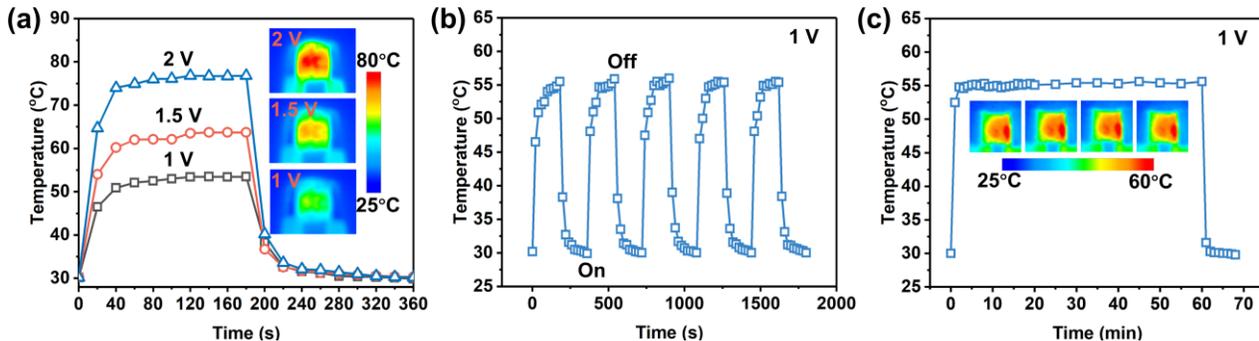
### ↓ 辐射加热性能测试



### ↓ 光热转换性能测试



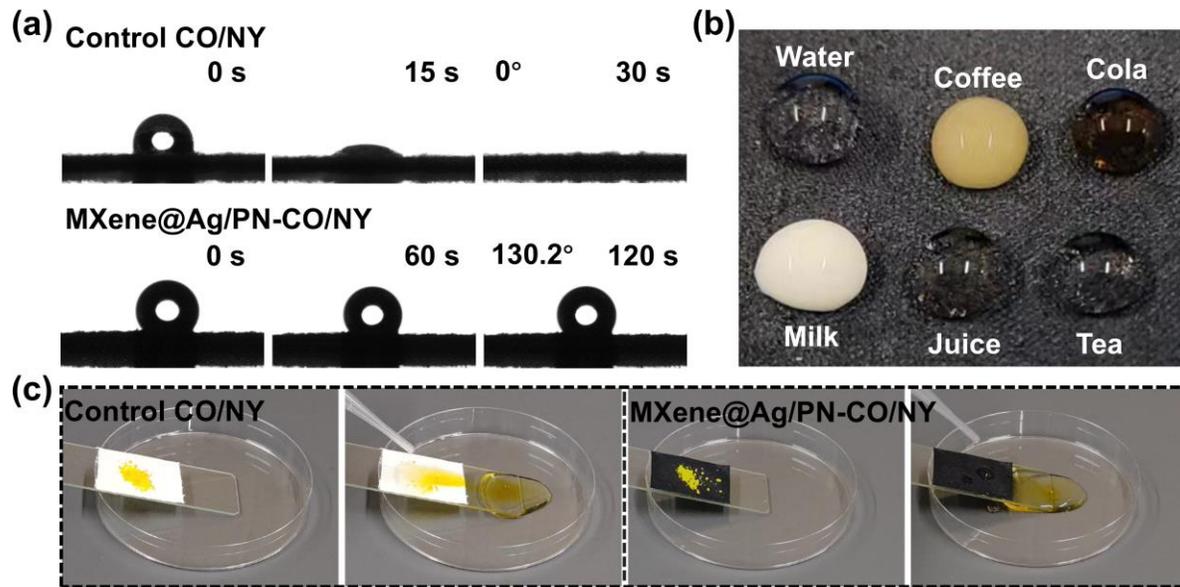
### ↓ 电加热性能测试



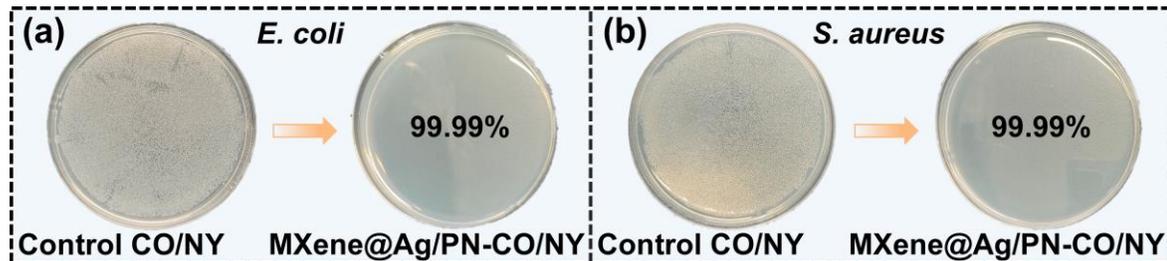
□ MXene@Ag/PN-CO/NY样品阻挡人体热辐射，起到保温效果

□ MXene@Ag/PN-CO/NY样品在电加热中将表面温度提升至 $76.8^{\circ}\text{C}$ ，在光热中温度提升至 $61.3^{\circ}\text{C}$

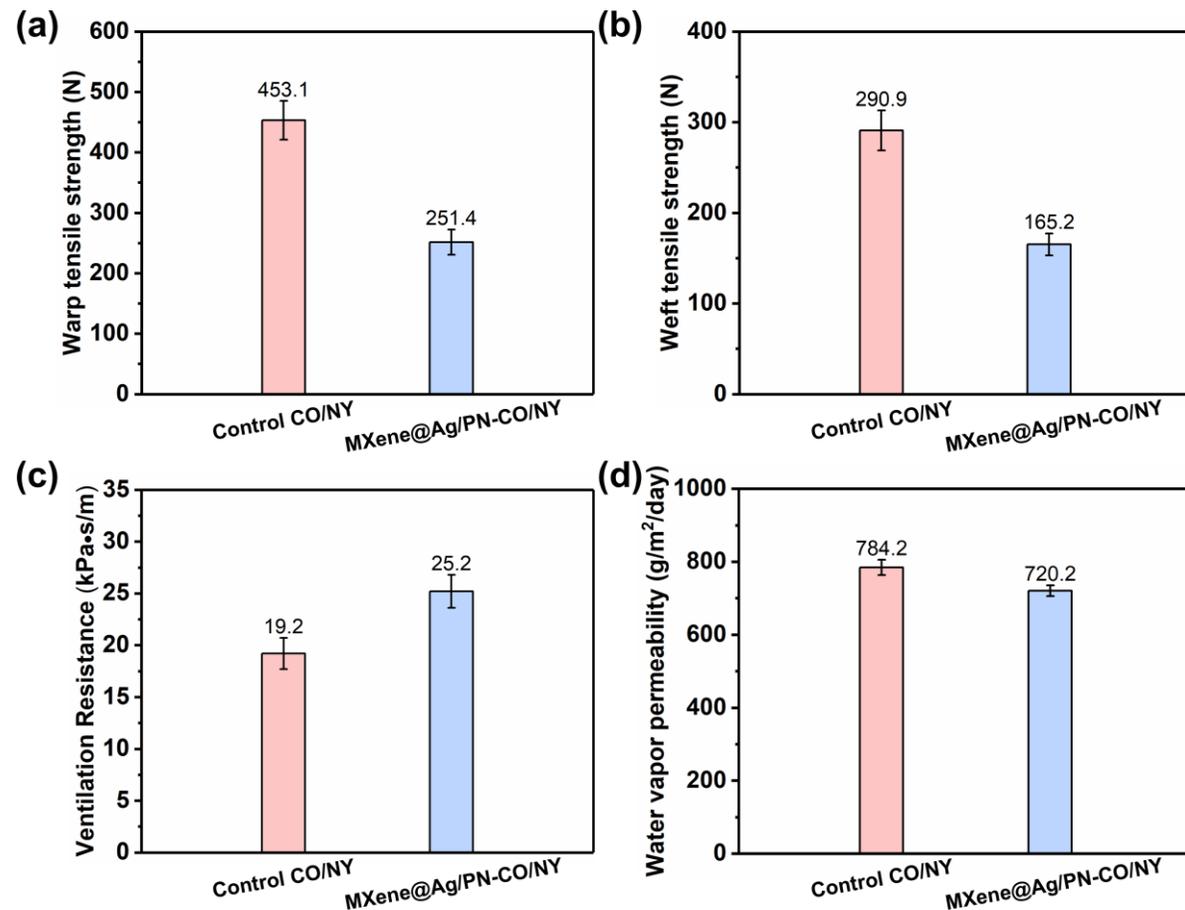
## ● 疏水性能测试



## ● 抗菌性能测试



## ● 物理性能测试



- 01** | 除了火安全外，还应关注织物的其他性能及功能
- 02** | 安全与环境友好是阻燃剂未来发展趋势
- 03** | 多功能阻燃纺织品按需而行



火安全材料研究中心

CENTER FOR FIRE SAFETY MATERIALS

感谢观看!

欢迎到北京化工大学指导交流

孙军 13699284362 (微信同号)

