EFFECT OF EPOXY/NANO-PARTICLE FILM INTERLEAF ON INTERLAMINAR PROPERTIES OF A CARBON FIBER/ EPOXY COMPOSITE

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Background

NASA Fixed Wing Project Goals for Propulsions Efficiency

Overall Project Goals-

Achieve a net aero-propulsive efficiency increase over conventional installation with minimal adverse

impaction weight and noise.

Task Objectives:

Increase aerodynamic efficiency of fan blade through a combination of a reduction in the thickness of composite fan blade- without adversely affecting toughness and impact resistance.

Approach

Thin, Toughened Fan Blade

- Nanocomposite/localized engineering of stiffness
- Aeroelastic tailoring

Benefit/Pay-off

- 1-2% reduction in fuel burn due to aerodynamic efficiency

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Approach to Improved Damage Tolerance of Composites

Materials Screening: Down-select a materials approach for interlayer toughening of composite fan blades.

- Nanoparticle Dispersion in a Thermoset Resin
- Thermoplastic Fiber Veil Interleaves.

Assessment: Tension, Compression, Short Beam Shear, GIC, GIIC

Goal: a reduction of damage on impact without reduction of in-plane properties.

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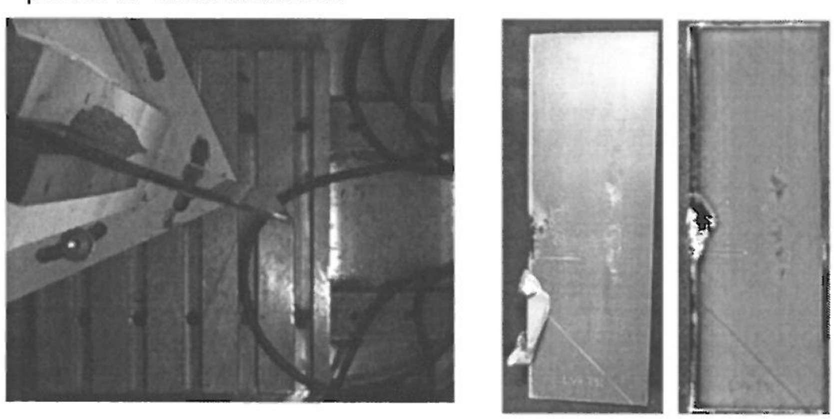
Benefit of Interleave Approach

- A material interleave approach is attractive because interleave is incorporated only where the structure is prone to delamination.



Gelatin based bird simulant projectile fired at 1080 ft/sec, with an angle of 66° from normal and 50% initial engagement.

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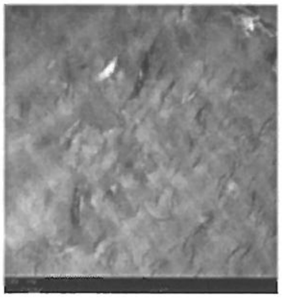
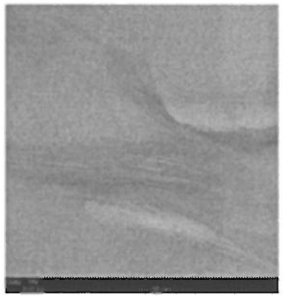
Characterization of Interleave Materials

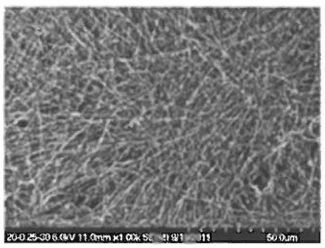




Epoxy/nano-particle films, ~ 4 mil thick.

TEM images of clay dispersed in toughened epoxy shows a reduction in dispersion with scale-up.

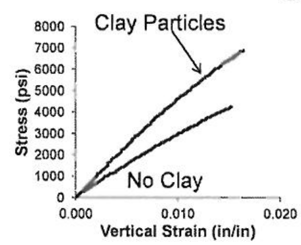
Interleave coupons included: Epoxy film, Epoxy/clay, epoxy/graphene, and epoxy/CNF.

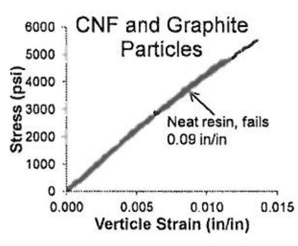


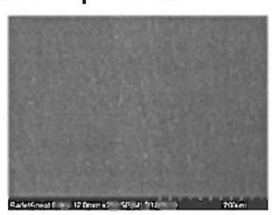
Thermoplastic veil materials have been investigated where the thermoplastic fiber diameter varies from nano to micron scale.

Areal Weight: ~ 1-10 gsm

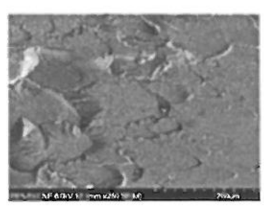
Nanocomposites Based on Aerospace Grade Epoxies

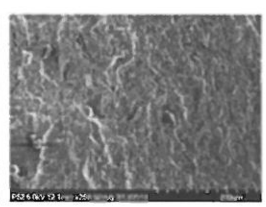






Fracture surface of nano-reinforced samples indicate increased material toughness





Graphite particles were epoxy functionalized via solvent-based wash. CNF particles were not functionalized.

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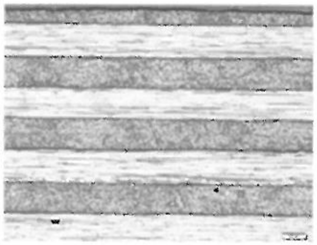
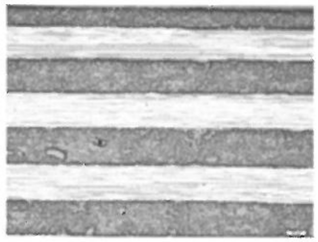
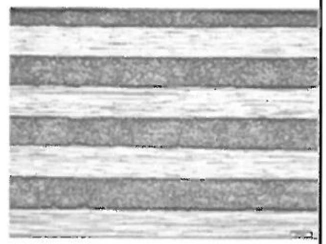
Optical Microscopy- Tension and Compression Coupons



Baseline Panel



Epoxy Interleave



PR19/epoxy interleave

Photomicrographs demonstrate:

- Void free panels
- Resin migration from interlayer.

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Resin Content- Short Beam Shear Coupons

Coupon	Density (g/cm^3)	Resin (wt.%)	Fiber (vol. %)	Void (%)
Baseline	1.58	34.7 (1.1)	58.0 (1.2)	0
Epoxy Film Interleave	1.47	56.5 (1.5)	35.9 (1.5)	0.4 (0.3)
Epoxy/Clay	1.47	55.2 (0.36)	37.1 (0.4)	0.5 (0.4)
Epoxy/Graphene	1.48	54.7 (0.50)	37.6 (0.4)	0.4 (0.3)
Epoxy/CNF	1.49	51.6 (0.53)	40.6 (0.5)	0.3 (0.2)

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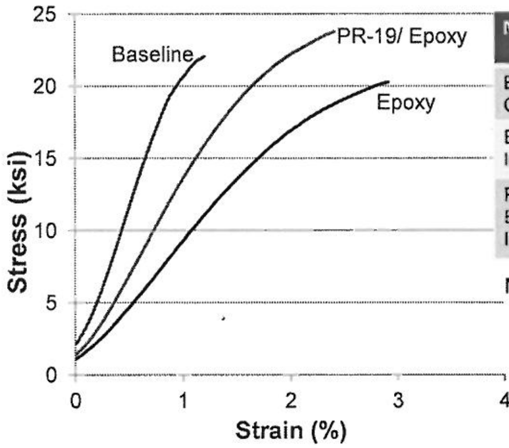
Epoxy and Nano-composite Interleave Short Beam Shear Results



Material	Max Stress (ksi)	Max Strain (%)	Modulus
Baseline Composite	21.4	1.1	21.6
Epoxy Interleave	20.0	2.3	8.1
PR-19/ Epoxy Interleave	23.5	2.3	12.7

Manufacturer data: 0°SBS Strength = 19.9 ksi

Laminate Configuration: $[0]_{24}$, resin film between each ply

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Acid Digestion

Tension and Compression Coupons

Laminate	Density (g/cm³)	Resin Content (wt%)	Fiber Volume (%)	Void Content (%)
Baseline	1.56	34.9 (0.6)	57.3 (0)	0.8 (0.1)
Epoxy Interleave	1.49	50.9 (0.6)	41.2 (0.6)	0.4 (0.3)
Ep-Clay Interleave	1.44	48.7 (0.15)	41.7 (0.1)	4.1 (0.6)
Ep-Graphene Interleave	1.51	48.6 (0.2)	43.5 (0.2)	0.2 (0)
Ep-PR19 Interleave	1.52	45.4 (0.13)	46.7 (0.2)	0.2 (0)

Laminate Configuration: $[0,90]_{4s}$, resin film between cross-plies

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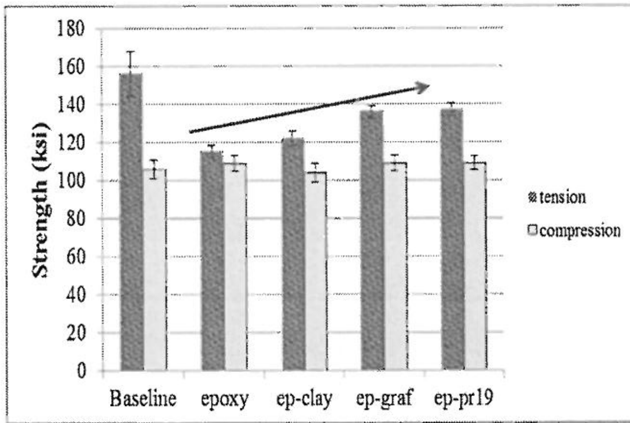
Epoxy and Nano-composite Interleave Tension and Compression Results



Laminate Configuration: $[0,90]_{4s}$, resin film between cross-plies

Normalized for fiber volume

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Double Cantilever Beam Results

Laminate	GI_C	GI_R
Baseline	184.4 (11.9)	315.3 (13.0)
Epoxy Film	127.2 (26.7)	208.6 (7.0)
Ep-Clay Film	78.2 (9.7)	87.0 (12.2)
Ep-Graf Film	111.0 (46.7)	273.6 (7.05)
Ep- PR19 Film	148.3 (15.9)	143.2 (9.3)

Significant reduction in Mode I fracture toughness with thermosetting interleave.

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Fracture Surface Analysis- Double Cantilever Beam Coupons

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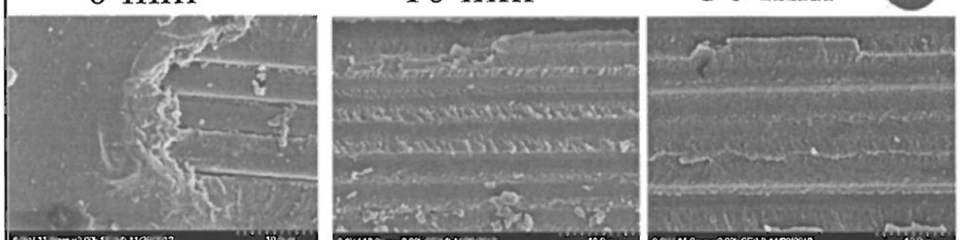
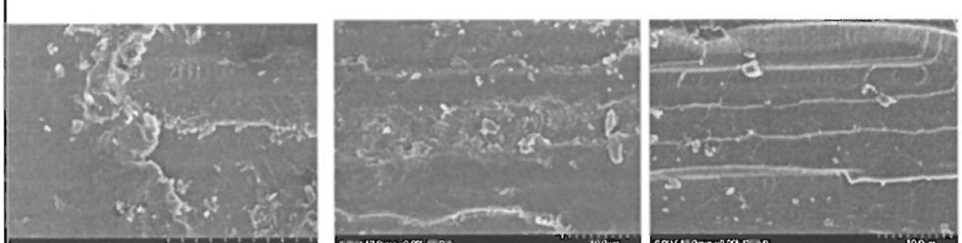
0 mm | 10 mm | 30 mm



Baseline (G_{1c} = 184, G_{1R} = 315)



Epoxy-Interleave (G_{1c} = 127, G_{1R} = 209)

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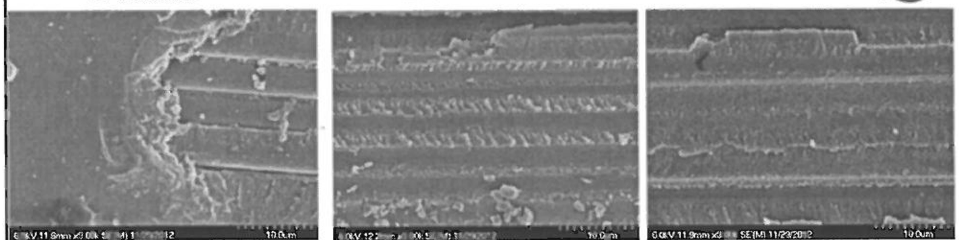
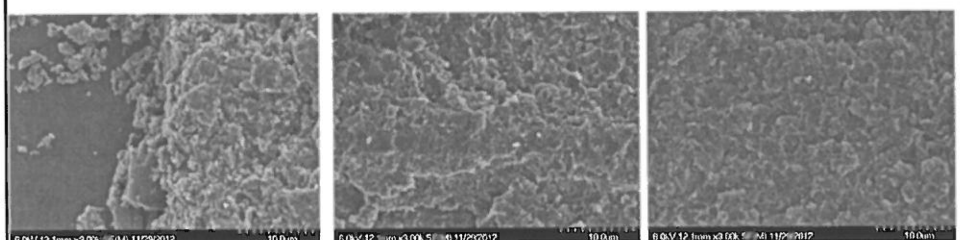
0 mm | 10 mm | 30 mm



Baseline (G_{1c} = 184, G_{1R} = 315)



Epoxy/Clay- Interleave (G_{1c} = 78, G_{1R} = 87)

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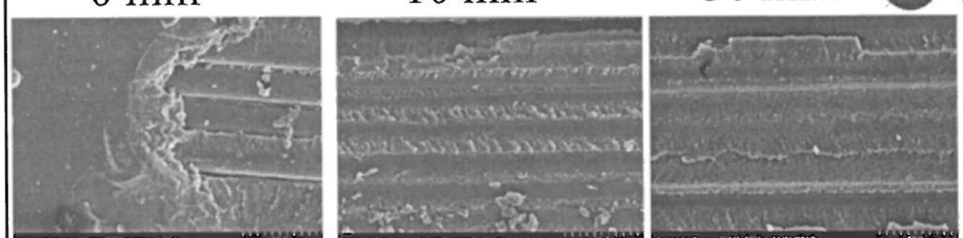
0 mm | 10 mm | 30 mm



Baseline (G_{1c} = 184, G_{1R} = 315)

Epoxy/PR19- Interleave (G_{1c} = 148, G_{1R} = 143)

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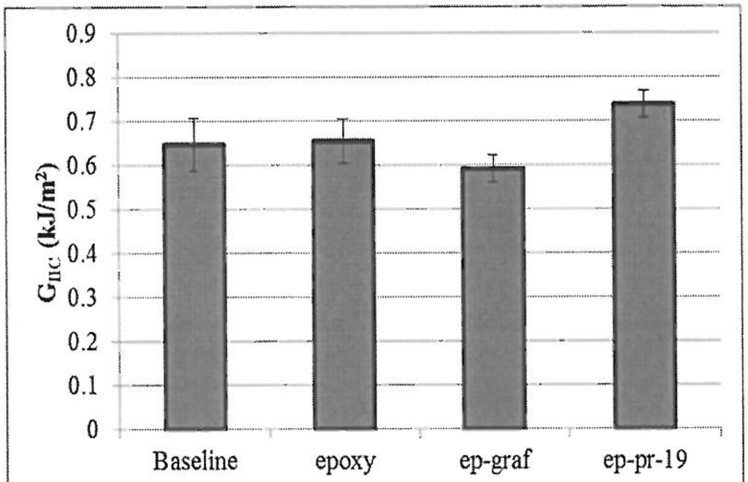
Mode II Fracture Toughness
End Notch Flexure Results



Modest nominal increase in Mode II fracture toughness through interleave of epoxy/CNF nanocomposite.

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Melt-Spun Thermoplastic Veils

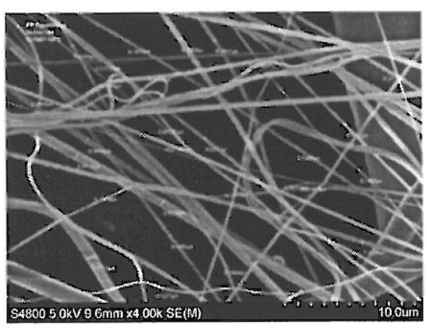

Photo taken from www.hillsinc.net/Fibers

Trials using 4 separate veil materials
Polypropylene: 1 gsm
Polypropylene: 4 gsm
Noveon
Polyethylene terephthalate (PET)

PET was the only material that did not dissolve into the epoxy at the 177°C cure temperature.

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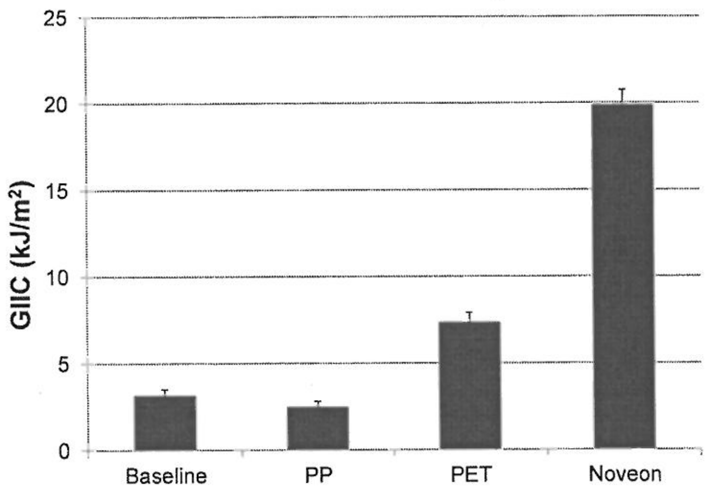
Melt-Spun Thermoplastic Veil Mode II Fracture Toughness



Noveon interleave resulted in a 7- fold increase in Mode II fracture toughness.

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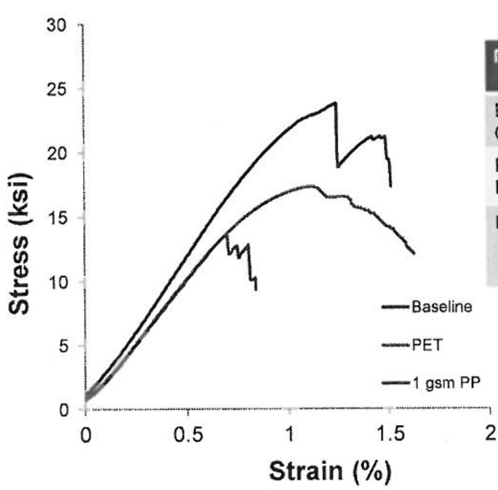
Melt-Spun Thermoplastic Veil Interleave Short Beam Shear Strength



Material	Max Stress (ksi)	Max Strain (%)	Modulus
Baseline Composite	23.5	1.2	22.7
PET Interleave	17.2	1.1	19.2
PP- 1gsm	13.1	0.7	17.8

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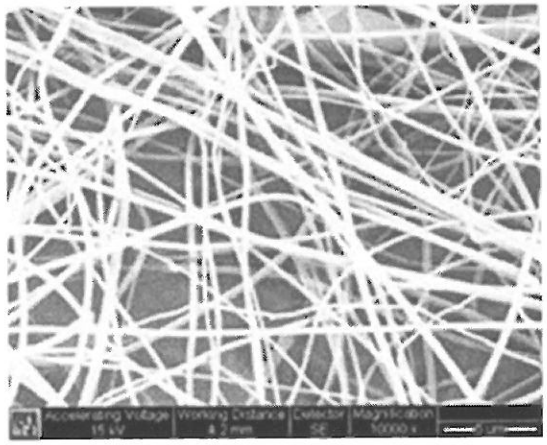
Electrospun PES Nanofibers



In Collaboration with Professor Kunigal Shivakumar, North Carolina A&T University

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Electrospun Nanofiber- Summary of Mechanical Properties

Properties		Base	Interleaved	% Change	Manufacturer's
Tensile Modulus, GPa		157 (7)*	153(5)*	-3%	164
Tensile Strength, MPa		2,557 (1)	2,694(3)	5%	2,723
Poisson's Ratio		0.31 (7)	0.29(6)		N/A
Compression Modulus, GPa		141 (2.4)	137(2.8)	-10%	150
Compression Strength, MPa		1517 (2.9)	1315(4.7)	-20%	1689
Interlaminar Shear Strength, MPa	0.0 wt % nanofabric	136.5 (2.5)	-----	-----	137.2
	0.5 wt % nanofabric	-----	140.6(1.1)	3%	-----
	0.8 wt % nanofabric	-----	140.0(1)	3%	-----
	1.1 wt% nanofabric	-----	138.6(1)	2%	-----

*% co-efficient of variation

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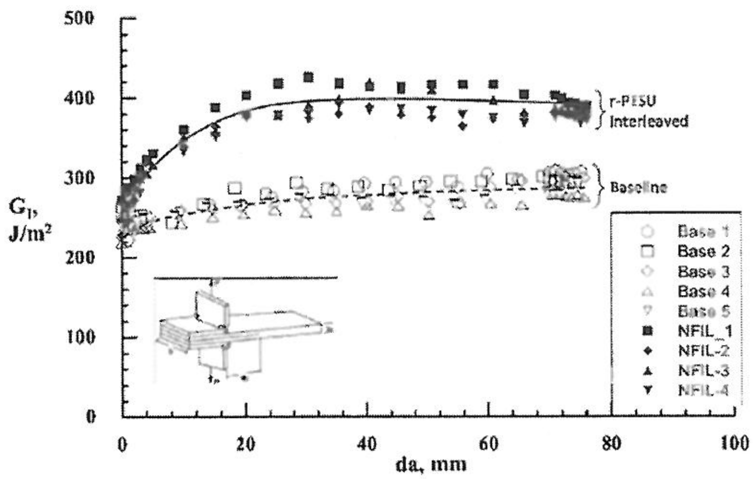
Electrospun Nanofiber- Double Cantilever Beam



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Conclusions

Three candidate material forms were interleaved into IM7/8552-1 and evaluated for their potential to reduce delamination on impact.

Nanocomposites composed of epoxy resin and a nanoparticle lead to the greatest reduction of in-plane properties and a modest increase to interlaminar properties.

Thermoplastic veils (melt spun and electrospun) offered improved interlaminar performance with minimal reduction of in plane properties.

Impact tests of down-selected thermoplastic veils will be performed over the next year.

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Acknowledgements

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