Frantsevich Institute for Problems of Materials Science
NAS of Ukraine

Research and development of current-conductive layered reinforced coatings based on micro wire composite cells that include nanostructure electric-conductive fillers to be used for repair and renewing of lightning damaged composite materials in structural elements of aircrafts

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Project's objective

The Project has as objective the study of an improved lightning protection system and the repair of polymer matrix composites due to the use of metal knitted meshes and disperse fillers in the form of current-conductive nanostructure particles.

Key words: Lightning protection, Polymer composites, Knitted meshes, Nanostructure particles, Gas-thermal spraying, Repair of aircrafts

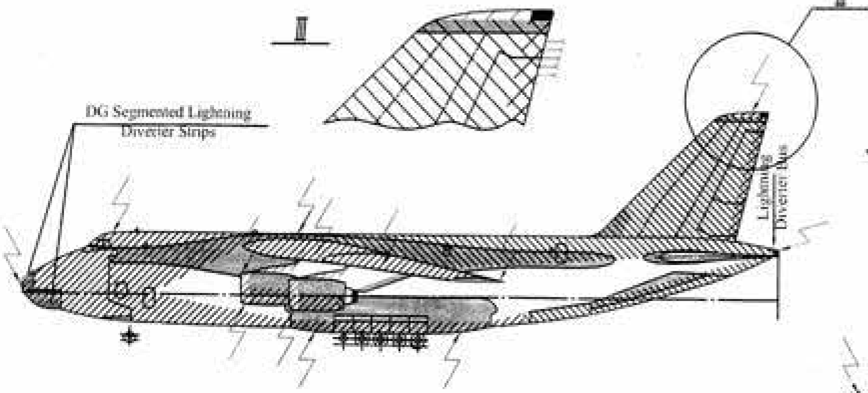
Motivations

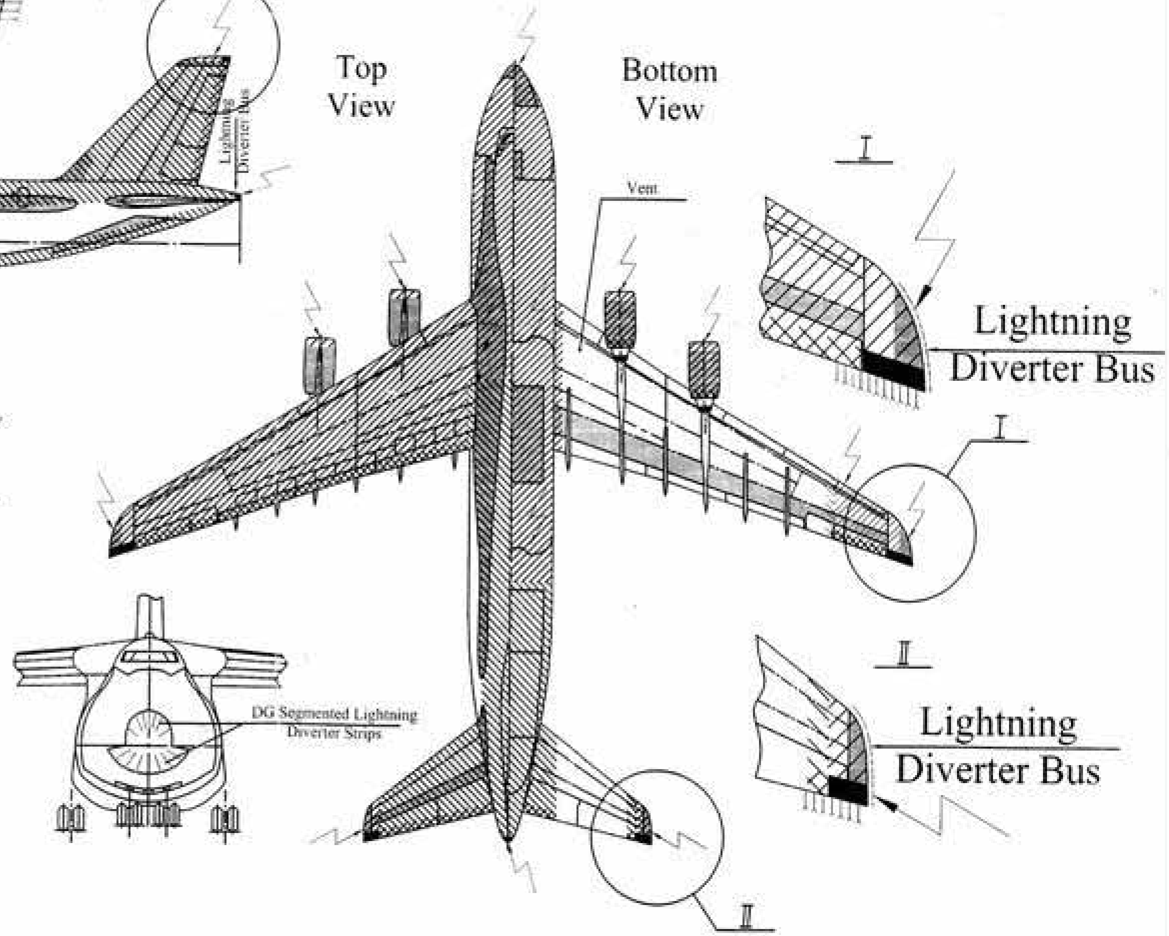
Increased use of carbon plastics in aircraft invokes an increased interest to the lightning strike protection for composite parts.

Unlike metals, carbon plastics when stroke by lightning are subjected to damages which are accompanied with splitting and delamination in the form of trough break-downs and consequently a separation of damaged layers by free-stream flows. The nature of carbon plastics damage is of thermal origin being a process of rapid binder destruction of material.

The development of protection systems for carbon plastics requires reliability and security for flights efficient cost and performance.

AN-124-100. Lightning Protection Diagram





Reference Designations

- *Zone 1A - All areas of the airplane surface where there is a high possibility of an initial lightning attachement with a low possibility of flash hang-on.*
- *Zone 1B - All areas of the airplane surface where there is a high possibility of an initial lightning attachement and a high possibility of flash hang-on.*
- *Zone 2A - All areas of the airplane surface where there is a high possibility of an lightning attachement being swept onto it from a Zone 1A, but having a low possibility of flash hang-on.*
- *Zone 2B - All areas of the airplane surface where there is a high possibility of an lightning attachement being swept onto it from a Zone 1A or 2A, but having a high possibility of flash hang-on.*
- *Zone 3 - All areas of the airplane not covered by Zones 1A, 1B, 2 A and 2B and having a low possibility of a direct lightning attachement.*
- *Coal-plastic parts*
- *- Fiberglass plastic parts*
- *- Points of leader orientation during tests*

Methods for protection against lightning strike

1-st group consists of metallic foils, perforated and stretchable meshes having a sprayed metal coating (aluminum, copper, nickel), metal knitted or woven meshes , copper and aluminum current-collector buses. Structural parameters of metallic or metal-containing layers such as thickness, perforation sizes, diameter of wire, pitch and layout of structural elements on the area surface and also methods of current collection depend on a given unity arrangement and the lightning strike behavior.

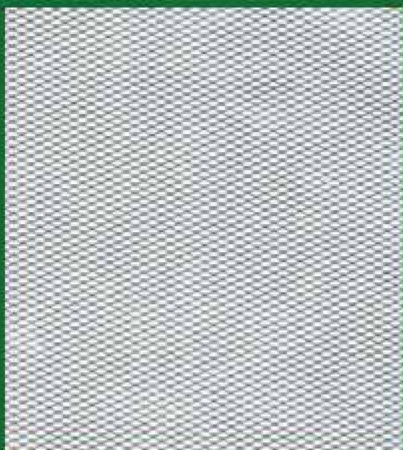
Methods for protection against lightning strike

- **2-nd group** comprises lightning strike protection coatings made of carbon having an increased values of electric conductivity and high heat resistance. As coatings, carbon fabrics with different layouts of fibers obliquely to the coating plane and stitched with threads having increased electric conductivity in transversal direction, are used.
- **3-d group** includes modification of binders of polymer composites through adding of nano-modification agents (fullerenes, nano-tubes) that increase conductivity of surface carbon layers of composite.

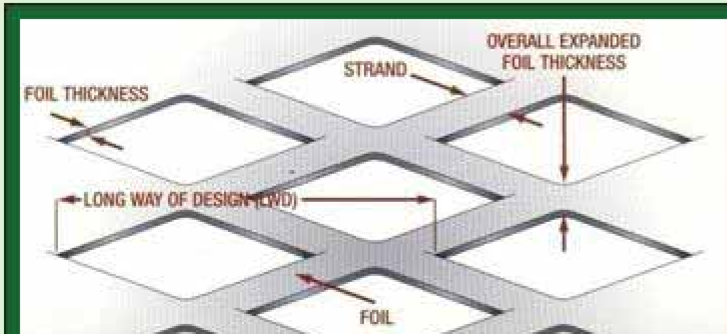
Each of above said system of lightning protection can not be for the all-purpose use relative to various units of airplane, though, while combining them rationally the required level of lightning strike protection is achievable.

Structure of metal lightning protection meshes

Stretching foils



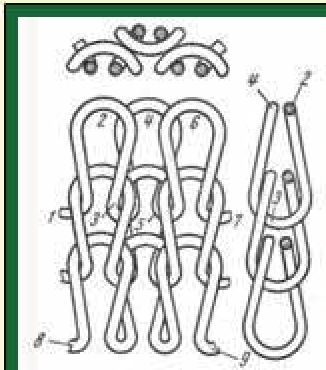

Strikegrid SG-2 Astrostrike Cu 029



Structure of stretching foil

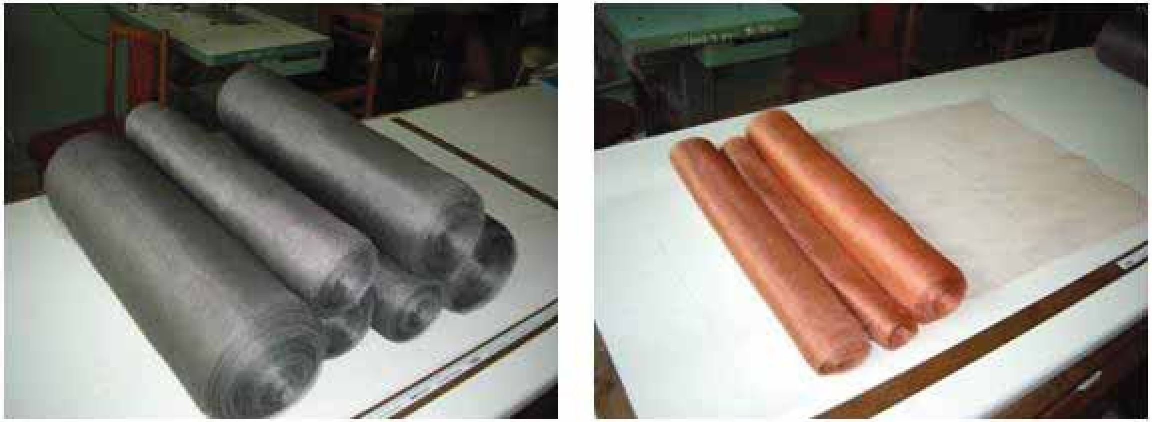
Knitted meshes


Copper 0.1 mm Copper 0.07 mm



Structure of knitted mesh by lasting 1+1 weave

Knitted meshes for lightning protection

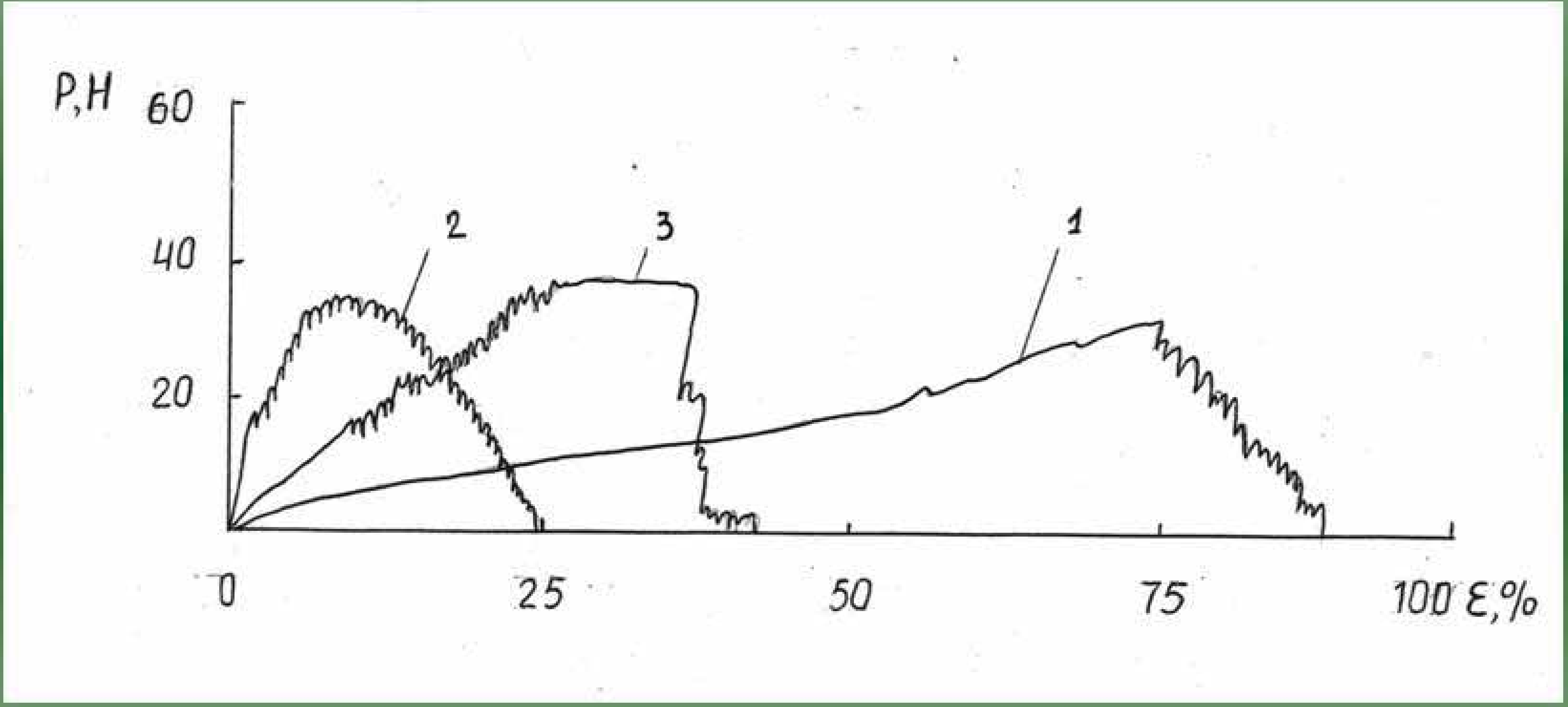


Knitted meshes in rolls

Knitting machine

Structure of knitted soldered mesh

Diagram of lightning protection meshes



1 – knitted mesh; dia 0.1 mm; 2- knitted/soldered mesh; dia.0.1; 3 - stretchable mesh Astrostrike Cu 029

Advantages of knitted-soldered meshes

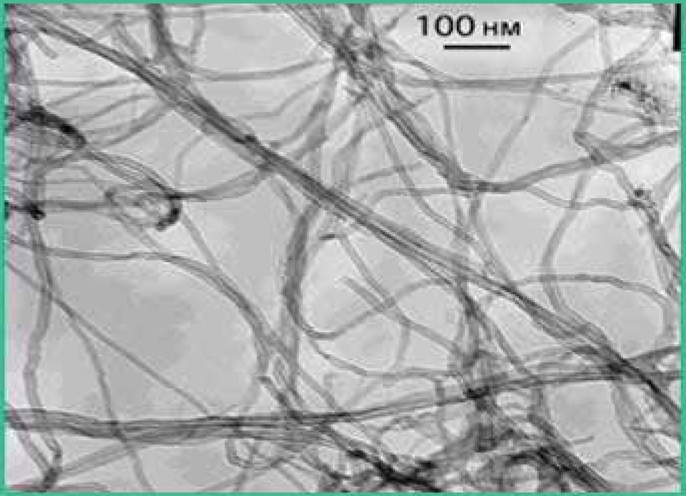
- Flexible loops of knitted meshes are able for stretching without rupture at high deformation efforts

- Cylindrical surface of wires distributes electric charge more evenly as compared to square sections of foil-type structural elements

- Solder covering the wire evaporates when heated and contributes lowering of heat energy

- Knitted-soldered structure favors relaxation of mechanical stresses and unlike rigid perforated or foil nets prevents to a great extent composite delamination and rupture.

Carbon nanotubes



Nanotubes, TEM

Characteristics of nanotubes

Bulk density, g/dm^3	20-40	29
Weight content of ash, %	8-22	18
Spec.surface of non-purified tubes, m^2/g	200-400	286
Spec.surface of purified tubes, m^2/g	200-400	273

Outer diameter, nm	10-40	10-20
Spec.electric resistance of non-purified nanotube, Ohm. cm	0.05-0.15	0.09
Spec. electric resistance of purified nanotubes, Ohm.cm	0.05-0,10	0.05
Temperature of weight loss after purification, ^{O}C	560-620	604

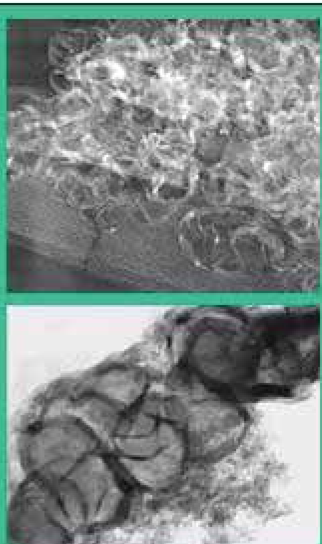
Carbon electric-conductive nanoparticles (IPMS NASU)

Initial materials:

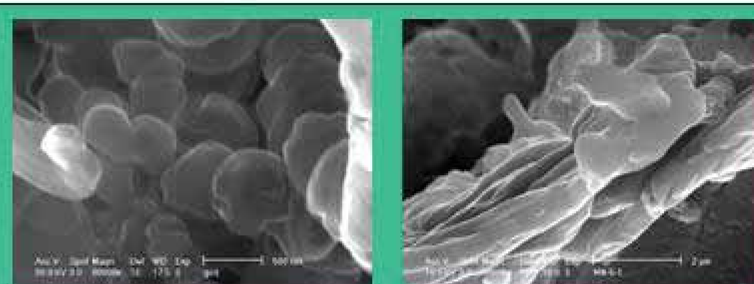
- hydrate cellulose fibers
- sawdust of wood

Main technology operations:

- Impregnation with catalyst solutions (metals of iron group)
- Pyrolysis at 600 to 800 °C
- Carbonization at 1000 to1400°C
- Atomization to the nano-scale



onions



nanographite

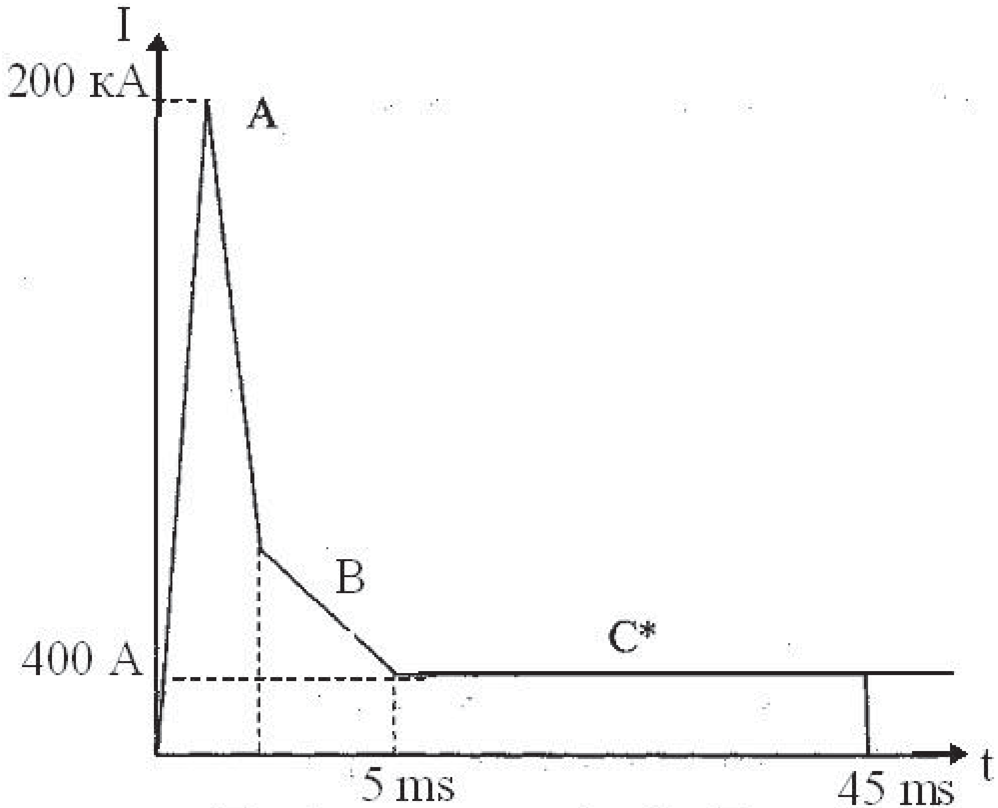
Characteristics of nanoparticles

Наименование	Bulk Density, g/dm^3	Specific surface, m^2/g	Dimension, nm	Specific electric resistance, Ohm·cm
Onions	50-80	150-300	Outer diameter 100-200 Wall thickness 10-20	10^{-3}
Nanographite	50-90	230-420	Pack thickness 10-100 Dimensions in base plane 500-800	10^{-3}

Samples to measure electric characteristics

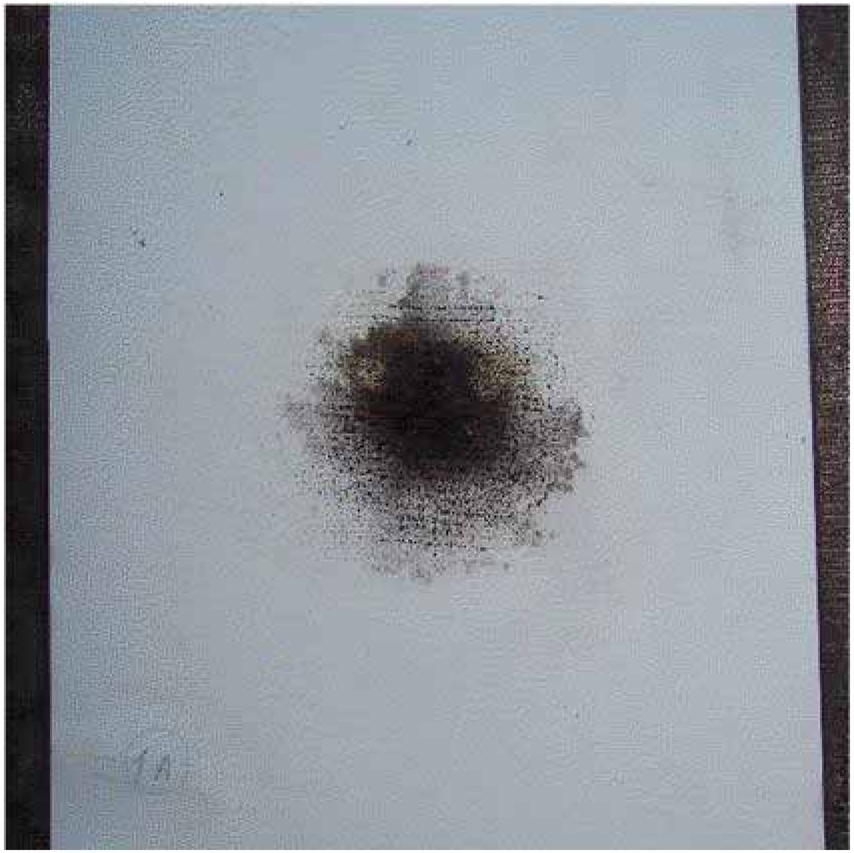
Bench for lightning discharge testing

Parameters of testing pulses

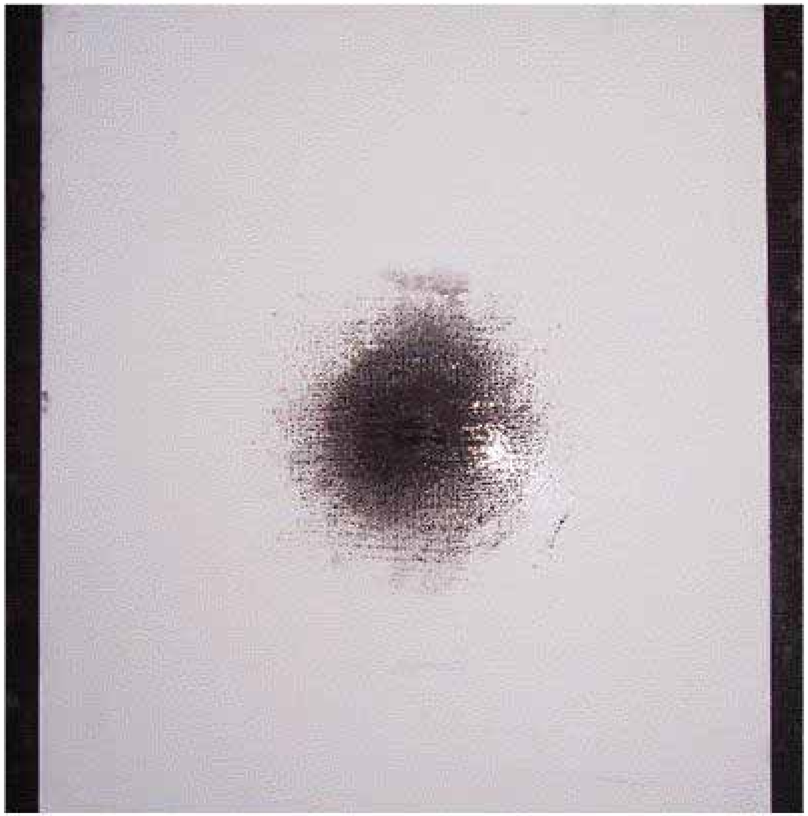


Testing current pulse for Zone 1A

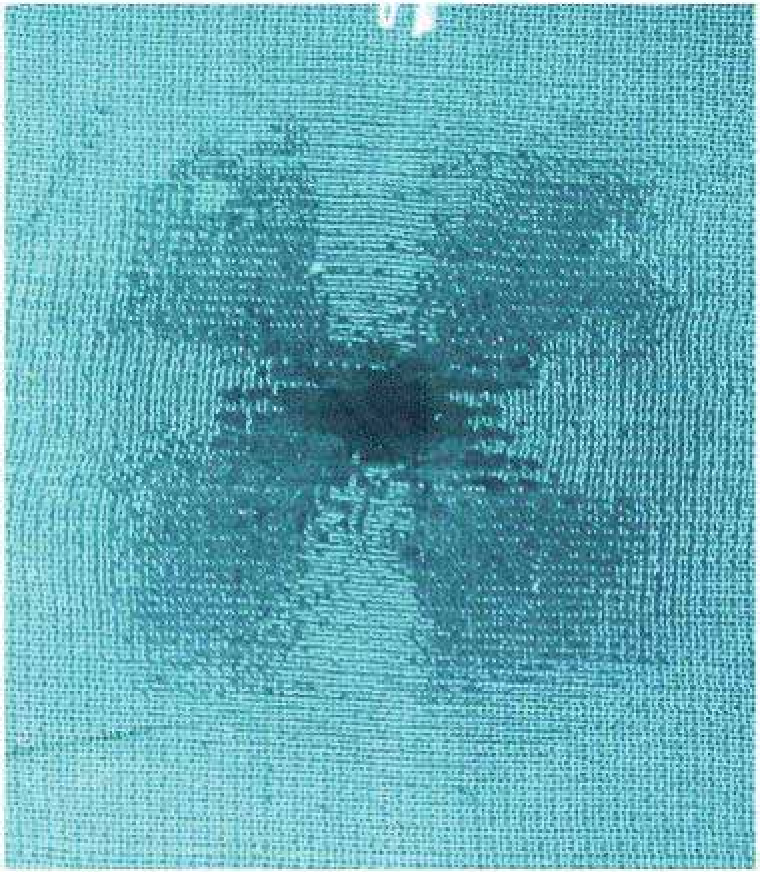
Panel including knitted soldered mesh after lightning strike testing (Zone 1 A)

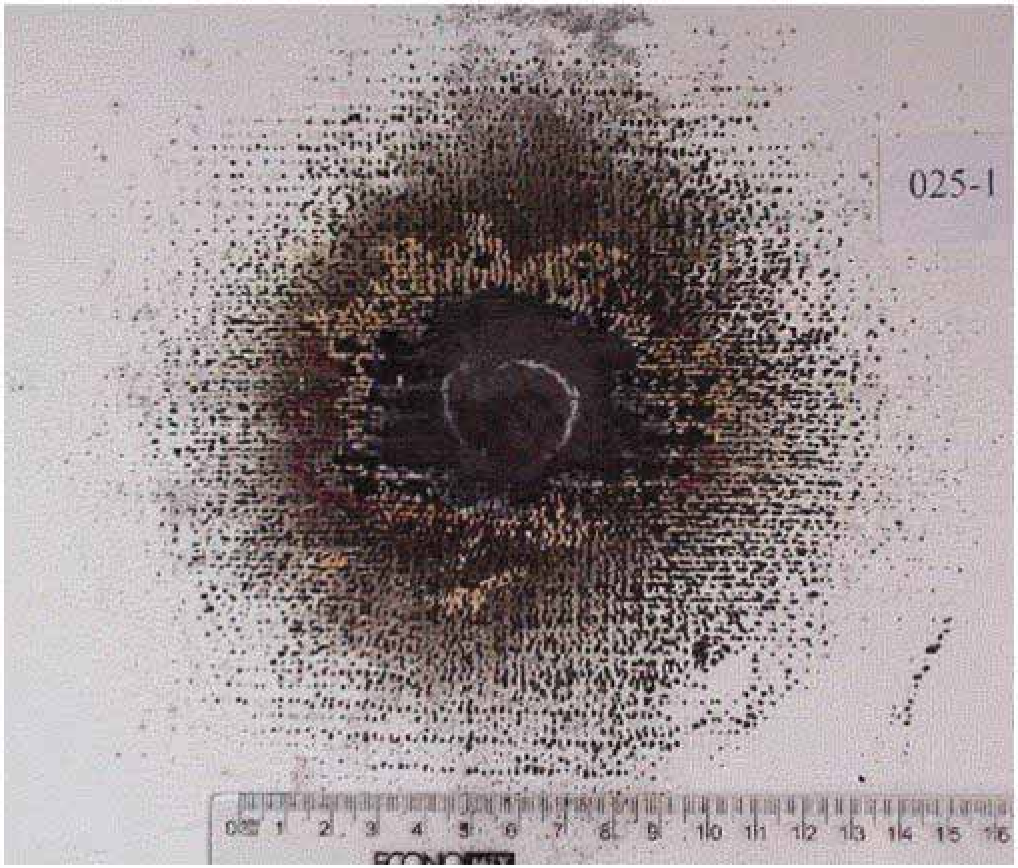


Panel including knitted soldered mesh and nanofillers in the form of nanotubes after lightning strike testing (Zone 1 A)



Panel after lightning strike testing to be repaired (Zone 1 A)





Typical results of testing panel prototypes (350×350 mm) (discharge as per parameters of Zone 1A)

# sample	Knitted meshes, nanoparticles	Weight, g			Area of destruction as per results of ultrasound control , cm^2	Thickness, mm		
		After covering	After testing	Loss of weight		Initial, mean	min in epicenter of attachment site	Depth of crater
1	Knitted mesh	250.97	246.75	4.22	20	1.125	0.6	0.525
2	Knitted mesh + nanoparticles	261.96	259.72	2.24	15	1.175	0.85	0.325

Analysis of data

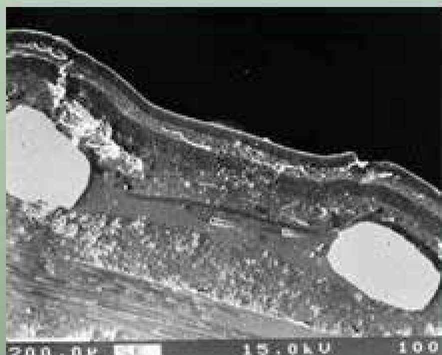
- No through puncture of panels ;
- Nanotubes reduce area of destruction when added.

Results of bench testing by simulating lightning strike Zone 1A

Characteristics of samples	Specific weight, g/sq.m	Ohmmic resistance of samples before testing, mOhm	Weight, g			Characteristics of influencing pulse	Thickness, mm	
			Before testing	After testing	Loss of weight	$I_{max}\ (кA)\ /\ /\int_{д} Z \times 10^{6}\ (A^{2} \cdot c)$	Initial	Depth of crater
Astrostrike	140	4.0	246.75	244.62	2.13	200.00/1.74	1,. 0	0.50
Knitted mesh	80	6.6	261.22	258.66	2.56	177.00/1.34	1.23	0,8

Structures of panels (TEM) after testing by lightning strike (Zone1A)

with Astrostrike Cu 029



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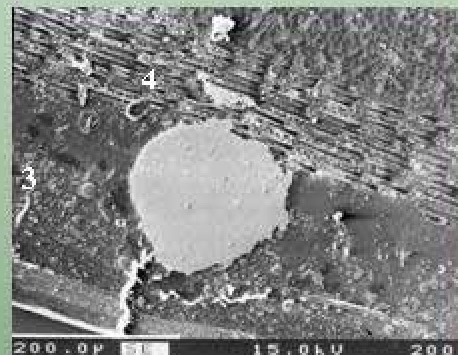
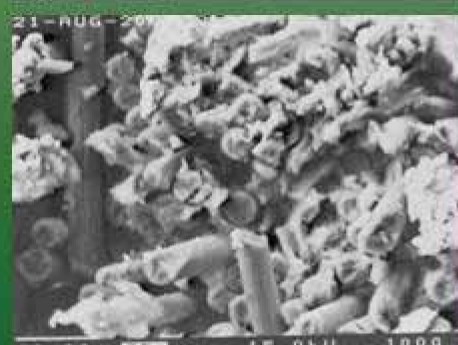
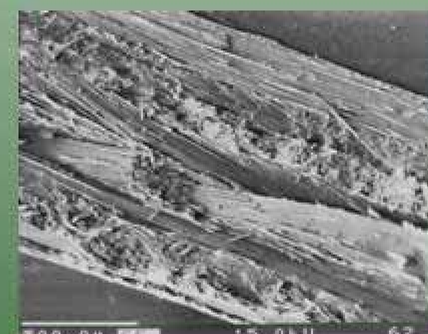
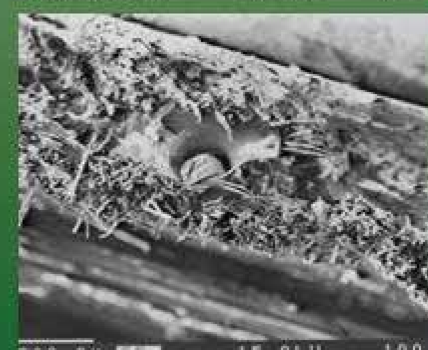
with knitted mesh





With knitted mesh and carbon nanotubes





Conclusions

The following works shall be considered under the Project:

- optimizing the structure and weight characteristics of knitted lightning protection meshes;
- offering efficient electric conductive nanostructure fillers for polymer composites;
- studying the mechanism of energy dissipation in carbon plastics composites having a lightning protection system when stroke with a lightning ;
- developing technology useful for the repair with the use of wire knitted meshes, nanostructure fillers and gas-thermal metal coatings.

The Project shall provide cooperation between Ukraine and EU under the Program AERO-Ukraine.