Advanced light-weight materials

The Council of Scientific and Industrial Research and the Advanced Materials and Processes Research Institute (CSIR-AMPRI) have developed and are in the process of developing light-weight materials that are in demand in a wide range of industry sectors – from sports goods and automobiles, to medical, aerospace, electronic and optical components, to name a few

CSIR-AMPRI

INTEREST in light-weight materials is increasing across industry and in research areas. Demand for light-weight, high performance materials in the Automotive, Aerospace, and Construction sectors and other related industries has increased multifold due to concerns in government regulations, environment, and consumer requirements.

Light-weight materials are a preferred choice for industries due to their weight reduction, energy savings, increased payoff loads, savings of natural resources, improved performances and environmental control aspects.

Light-weight materials include polymers, ceramics, aluminium and its alloys, magnesium and its alloys, composites and ultra high strength steel. They successfully replace steel and cast irons, lead, brass, bronze parts, and heavy duty concretes with 20-80 percent reduction in weight.

Researches adapt suitable methodologies such as improved alloy design, advanced processing technique, development in heat treatment schedule, advanced casting, secondary processing, heat treatment etc and intelligent materials and processing.

Intervention by CSIR-AMPRI towards further developments in these methodologies are active in Al-alloys and composites, Magnesium alloys and composites, Al-foams, Carbon foams, Ti-foams, Foam core sandwich panels, Squeeze casting, EMF forming, and Shape memory alloys.

Light-weight materials have found their applications across various domains – from sports goods and automobiles, to medical, aerospace, electronic and optical components. A few are listed here.

Sports: Golf clubs, tennis rackets and the handles of archery bows, bicycle frame and the chassis of in-line skates

Automobiles: Engine block, wheels, steering columns, seats, front consoles, and hoods, gearboxes, steering columns, and driver's air bag housings as well as in

steering wheels, seat frames, and fuel tank covers.

Medical: Biodegradable plates and screws for orthopaedic surgery

Aerospace: Magnesium can be found in the thrust reversers for the Boeing 737, 747, 757, and 767, as well as in engines and aircraft and helicopter transmission casings, intercontinental missiles and spacecraft.

Advantages of light-weight materials

• Density: 1.75 to 1.8 g/cc (lightest structural materials, even lighter than FRP)
• Room temperature strength equivalent to that of aluminium alloys
• Lower cost, high damping capacity, vibration and noise reduction, improved EMI shielding
• Huge energy savings, cost competitive, increase payoff load, biocompatible

Current problems

• Highly reactive (greater safety and precaution to be taken during processing)
• Poor high temperature stability
• Inferior creep properties
• Highly corrosive

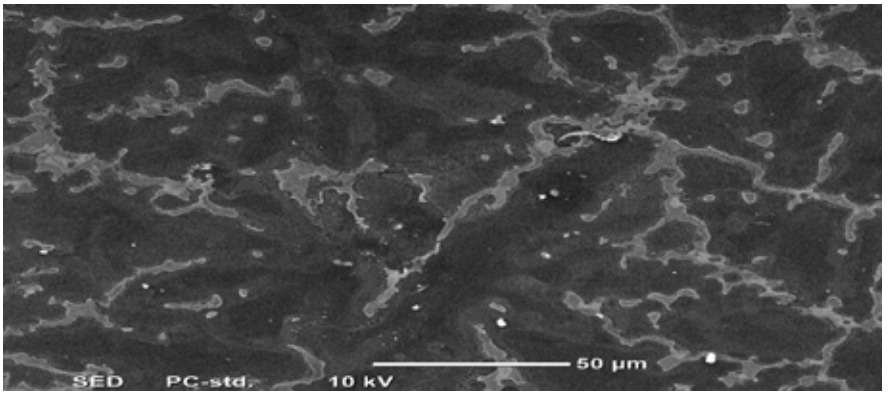
Solutions

• Melting and casting under controlled atmosphere, reduce oxygen pressure over melt – (direct metal pumping to the mould – inert atmosphere in the mould)
• RE and TE alloying addition – Pressure die casting: (thin walled casting), SPS (corrosion resistant Mg alloy)
• RE: Zr, Nb, Ce; TE: Ca, Mn, Zn; Coating: Anodising
• CSIR-AMPRI has developed the capability of melting and casting of these alloys without any difficulty
• Solid casting: Addition of 5wt% Si led to 50 percent improvement in strength of AZ91 alloys

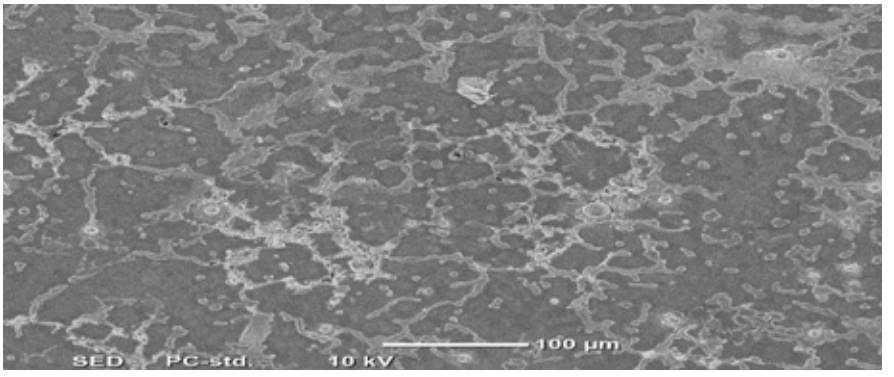
APPLICATIONS OF LIGHT-WEIGHT MATERIALS

MAGNESIUM ALLOYS AND ITS APPLICATIONS

AZ91



AZ91+0.3% Si



AZ91 + 0.3% Si (Micro structural refinement, almost 60 percent improvement in hardness/strength)

High speed train

• The newest train includes six passenger carriages, and the front end is tapered to a fine sword-like point
• The power of this train is 22,800 kilowatts
• It is constructed of lightweight plastic (Mg alloy and reinforced with carbon fibre)

Benefits

• 1/5th the weight of steel
• RE and TE improve flame retardance, creep resistance, and corrosion resistance
• Less noise and sound, good damping capacity

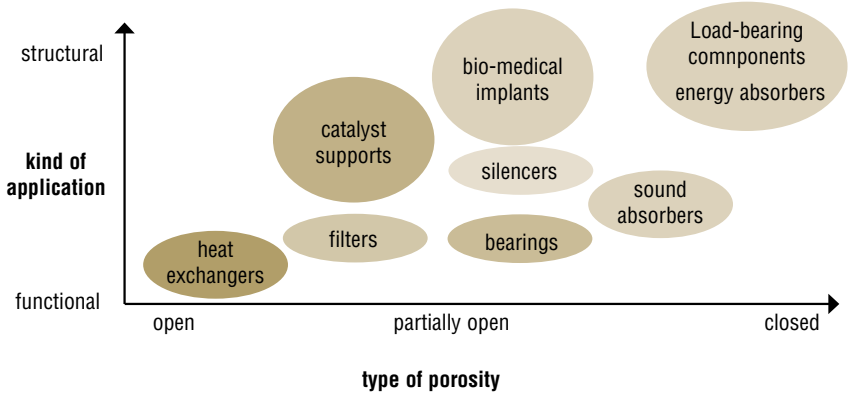
Mg-alloy melting

• Simple flux melting and casting can be adopted
• Parameters optimised for melting, bottom pouring would be best way
• Thin wall casting could be done using low pressure die casting
• AZ91 when added with 5wt% Si the hardness increase from 80 HV to 135 HV.
• The same methodology could be adopted for making composite and foam

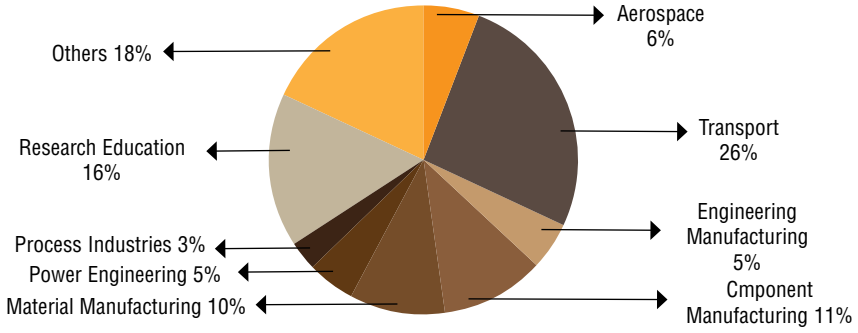
METALLIC FOAM AND ITS APPLICATIONS

Brass foam for water treatment

Major applications of metallic foam



Major applications of metallic foam



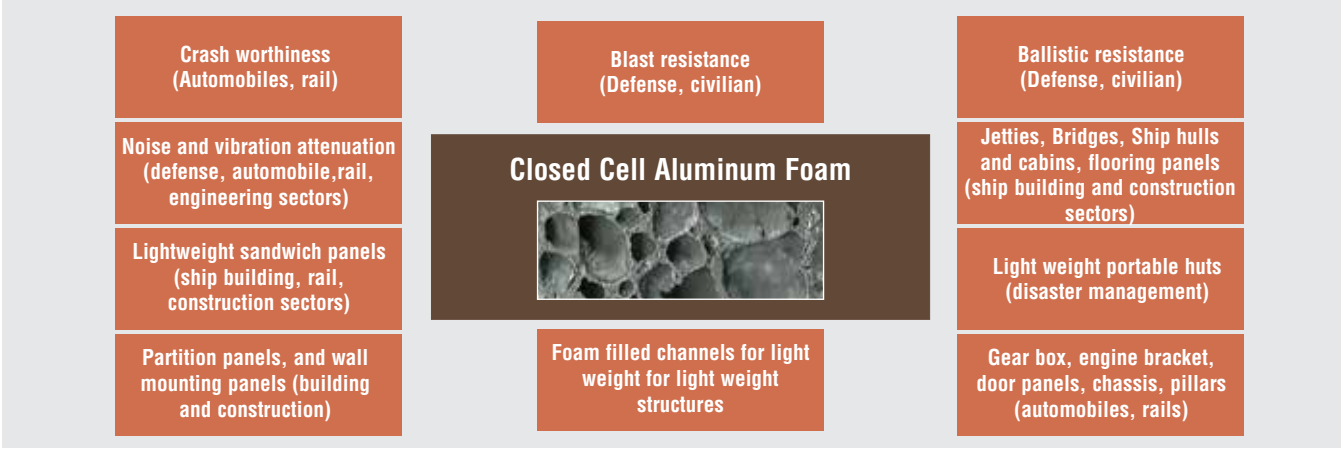
Ti-foam: Bone implants, teeth grafting, catalyst, high temperature filters and high energy absorptions

Ni foam: Battery, heat exchanger

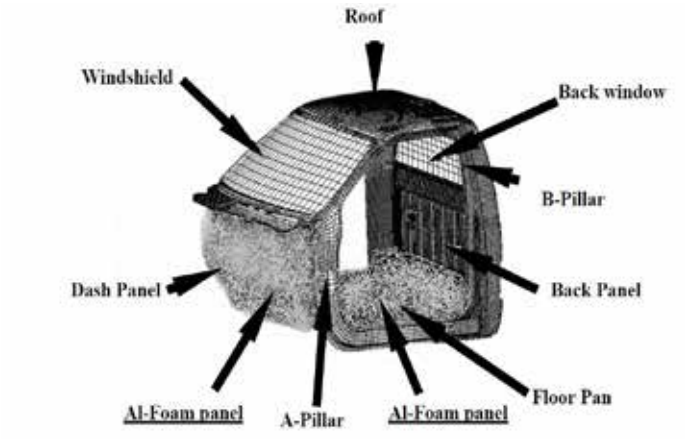
Al-foam and Copper foam: Heat exchanger, gas scrubber, solar heat arrester, hydrogen storage, energy absorption, vibration and sound attenuation, lightweight structure

ALUMINIUM FOAM AND ITS APPLICATIONS

Closed cell aluminium foam

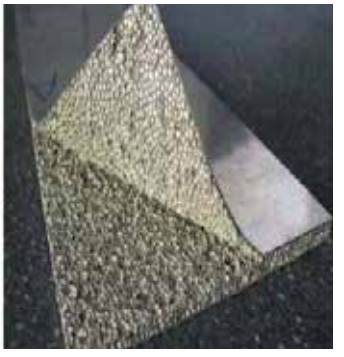


Possible locations for Al-foam in automobile applications



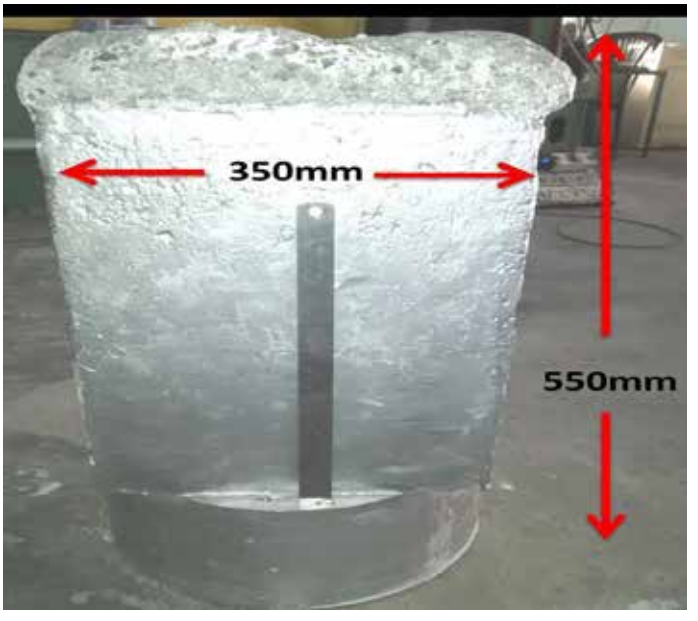
Foam filled tubes

Sandwich panels



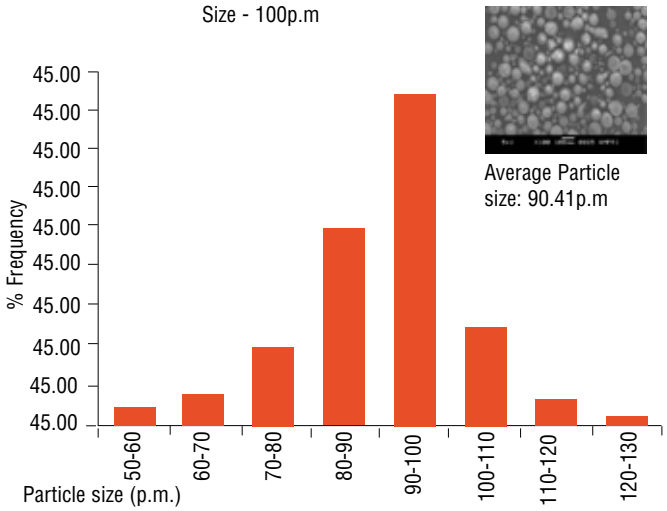
Engine bracket

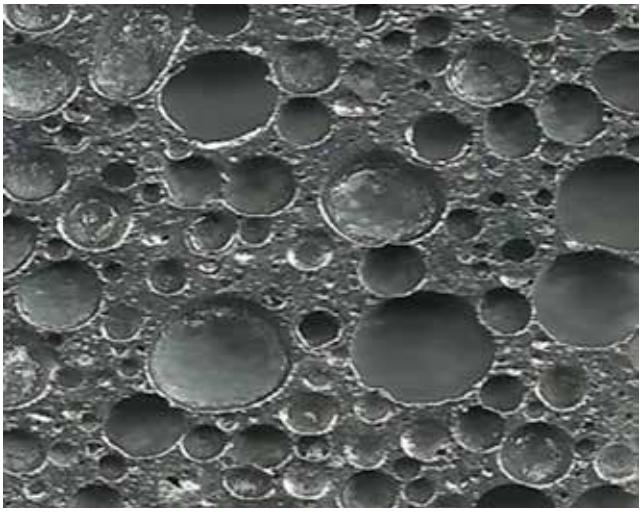
Large size foam billets

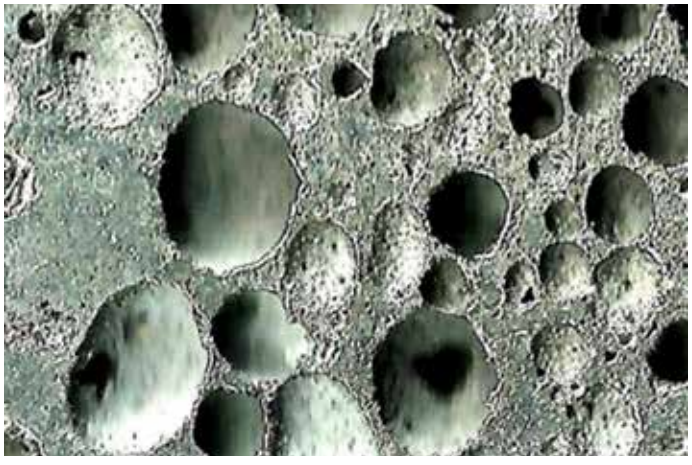


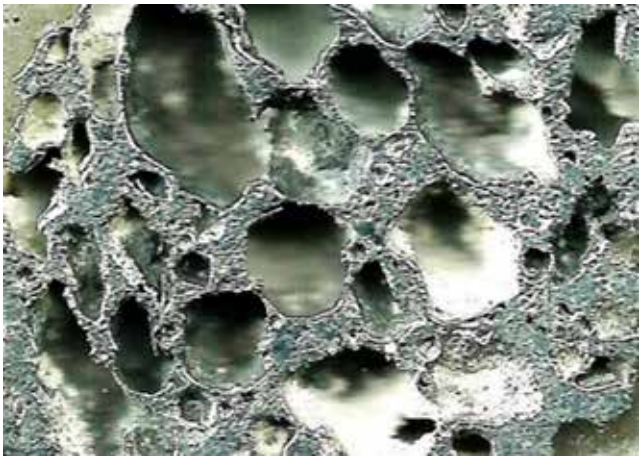
Foam Casting weighing 30kg

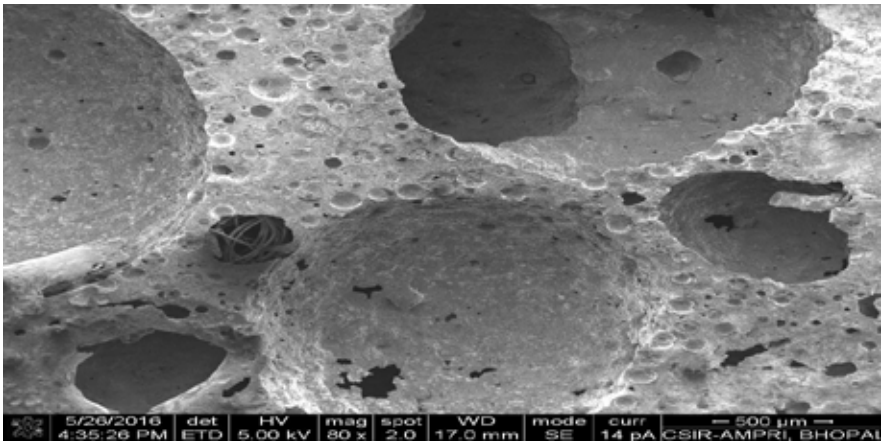
FOAM SAMPLES AND MICROSTRUCTURE











Factors affecting foams structure

(i) Melt temperature
(ii) Viscosity (concentration of thickening agent)
(iii) Cooling rate of foam structure

Benefits

- Cost of foam reduced to Rs800 per kg
- 200 g of cenosphere/fly ash per kg could be used

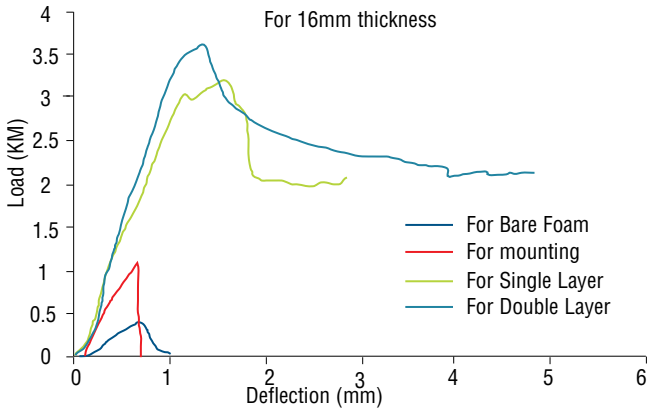
Aluminium foam property (comparison with internationally available foam)

Sl no.	Property	AMPRI-foam	Aluminium light foam
1	Yield strength/plateau strength (MPa) (compression) at strain rate of 0.001/s	4 – 25	3 – 26
2.	Flexural stress (MPa)	5 – 25	5 – 28
3.	Energy absorption (Mj/m3)	2 – 18	
4.	Density (g/cc)	0.20 – 0.7	0.2 – 0.75
5.	Modulus (GPa)	0.2 – 5.0	0.15 – 5
6.	Cell size (mm)	1.5 – 5.0	1.0 – 5.0

Foam core sandwich panels

Sample	Density of the sample (kg/m3)	Load (kN)	Bending stiffness (N-m2)	Specific stiffness (m6/s2)
Bare foam	428.11	0.442	9.728	0.0227
With mounting	574.7	1.11	26.34	0.0458
With single layer	612.94	3.236	32.18	0.0525
With double layer	707.4	3.63	41.533	0.0587
Bare foam	365.32	0.501	12.18	0.033
With mounting	554.91	1.34	28.89	0.052
With single layer	603.17	3.3	36.31	0.0602
with double layer	651.58	5.33	62.26	0.0955
Bare foam	303	0.8	15.73	0.052
With single layer	501.3434	3.77	39.21	0.0782

Foam core sandwich panels

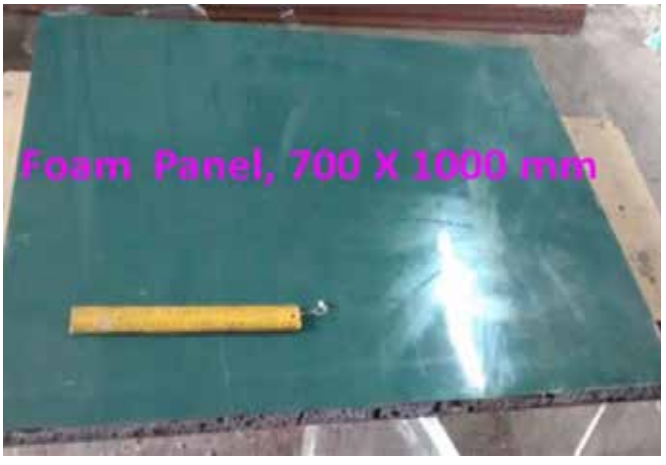


Al prototype products made

Foam billets made at 80 percent reproducibility, large size foam billet preparation demonstrated

Foam blocks supplied to Tata Motors

Aluminium foam core 2014 Al-alloy (0.5 mm thickness) faced sandwich panels (size 1m x 2m x 0.025 m) (areal density: 3.5 kg/m2)



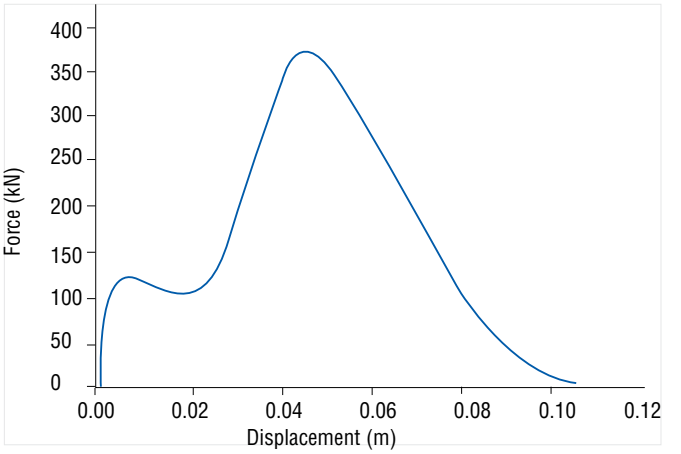
FRP faced Al-foam core sandwich panel, 30 mm thickness (areal density: 7.0 kg/m2)

PROJECT-1

Drop weight test of empty/foam filled crash box

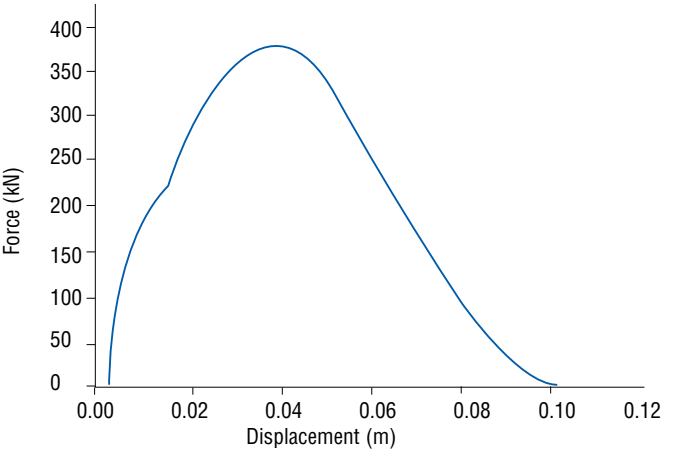
Empty/foam filled crash box

Energy absorption: 9.8 kJ



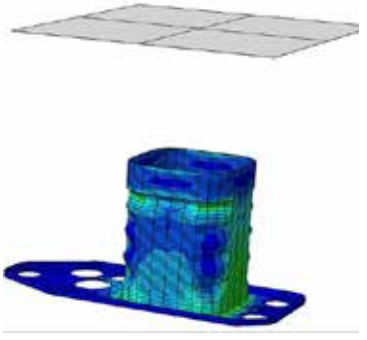
Foam filled crash box

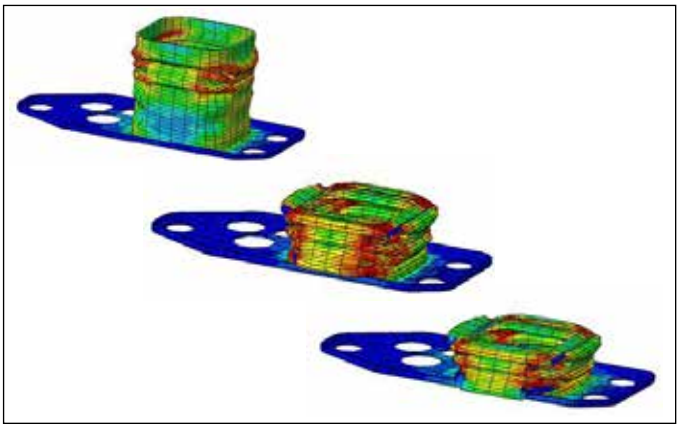
Energy absorption: 19.8 kJ



FEM results

Energy dissipation: 2 times





FEM results

130mm crash box > 35mm

Same as experimentally determined

Use of 400 gm of foam
Crash box weight: 800 gm

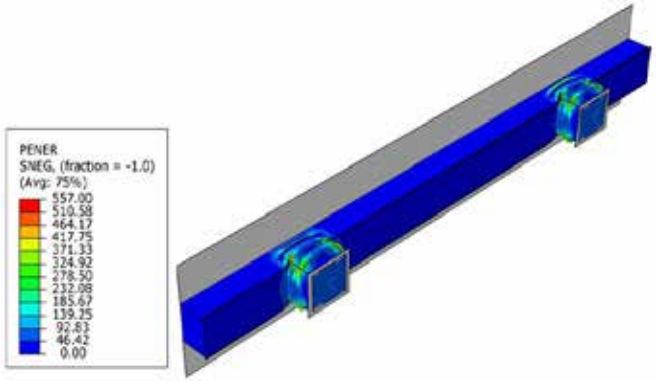
Energy absorption with foam filled > double

PROJECT-2

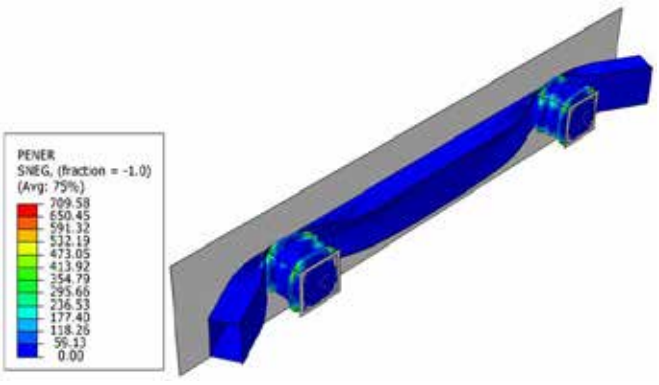
FEM simulation
Empty/foam filled bumper and crash box assembly

Car crash analysis: Euro NCAP Standard (135-165 kJ)
Energy dissipation at 150 mm deformation

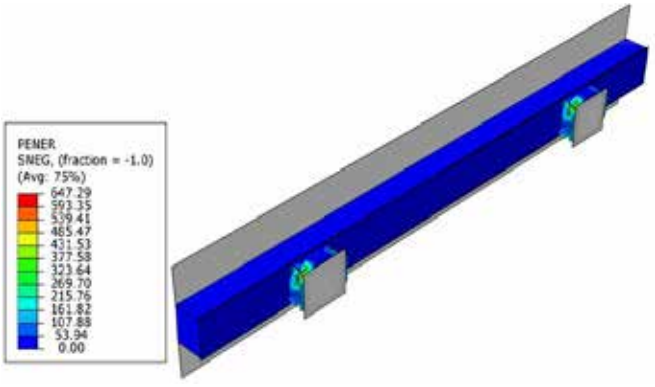
Case1: Foam: Bumper + crash box (200 kJ)



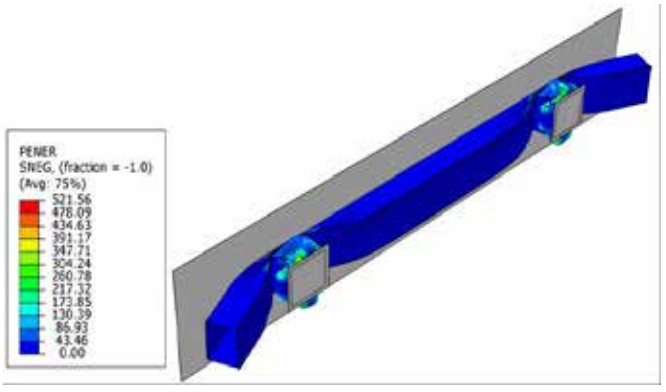
Case 2: Foam: Only crash box (97 kJ)



Case3: Foam: Only bumper (16.5 kJ)



Case4:-Empty: Bumper + crash box (11 kJ)



Product samples

Foam filling methodology established, simulation done

Tata Motors will be conducting tests

(1500 gm of foam insert ~ 200 kJ)

ALUMINIUM MATRIX COMPOSITES

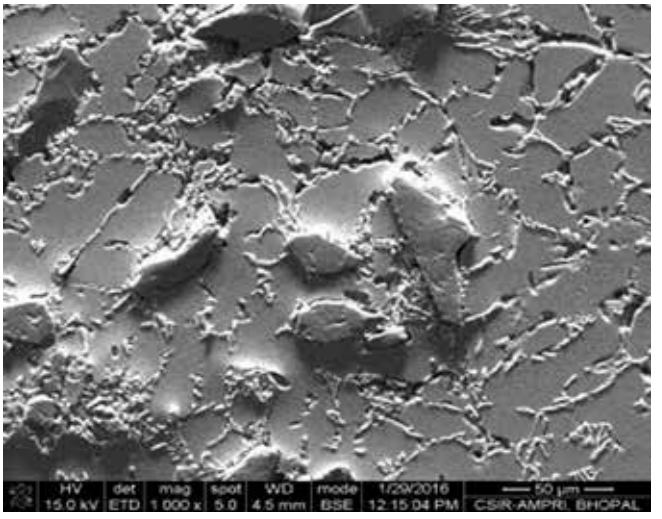
Advantages
- Light-weight
- Higher specific strength and stiffness
- Higher damping capacity
- Comparable TEC to steel and cast iron
- Higher wear resistance

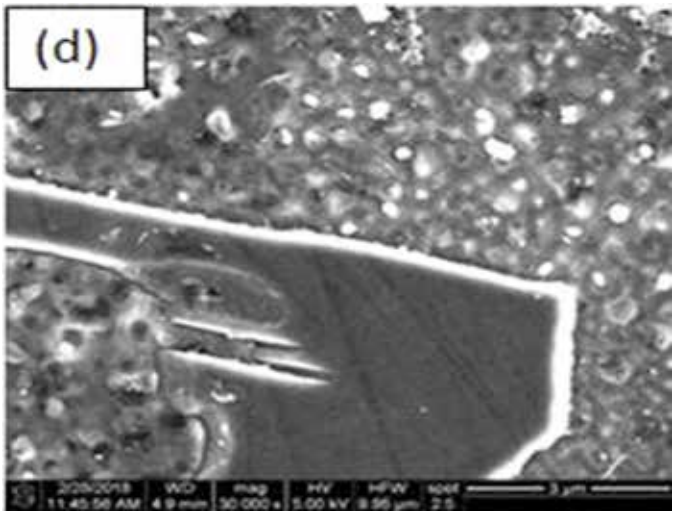
Limitations
- Uniformity in reinforcement distribution
- Interface bonding
- Poor machinability light-weight

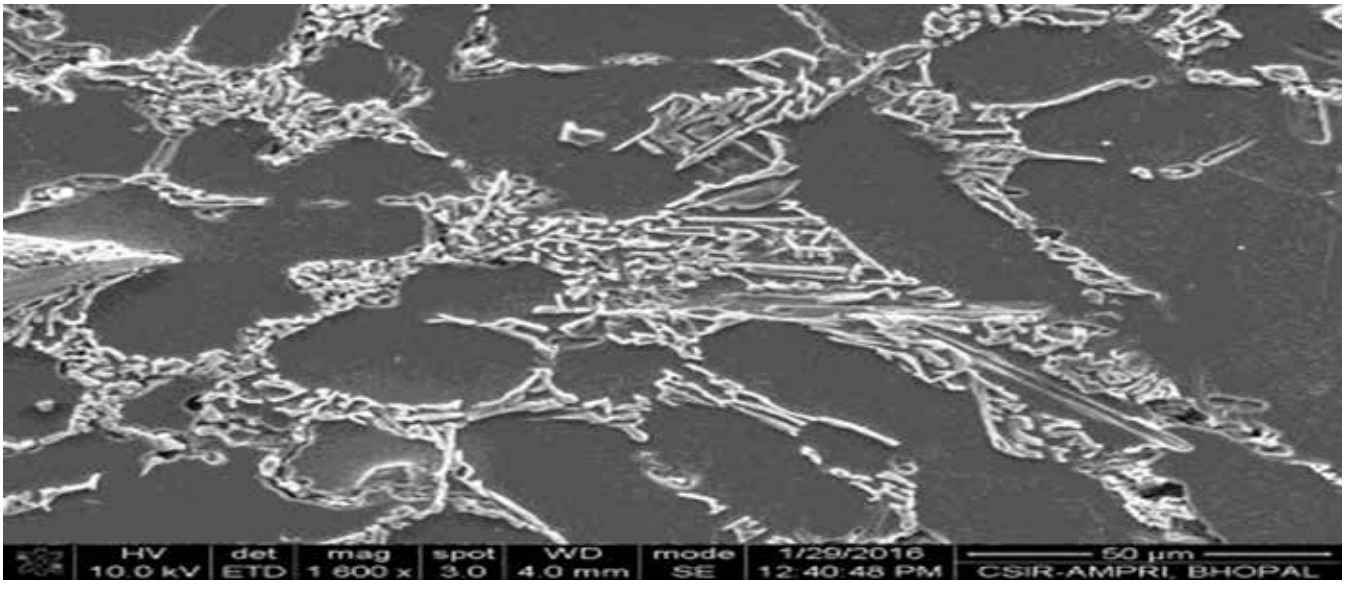
Solutions
- Near net shape casting and forming
- Squeeze casting/pressure die casting/ thixocasting
- Nano particle dispersion using secondary dispersion
- Ultrasonic stirring

Probable automobile components
Connecting rods, cylinder liner, engine blocks, brake drums/discs, pistons, clutch plates etc

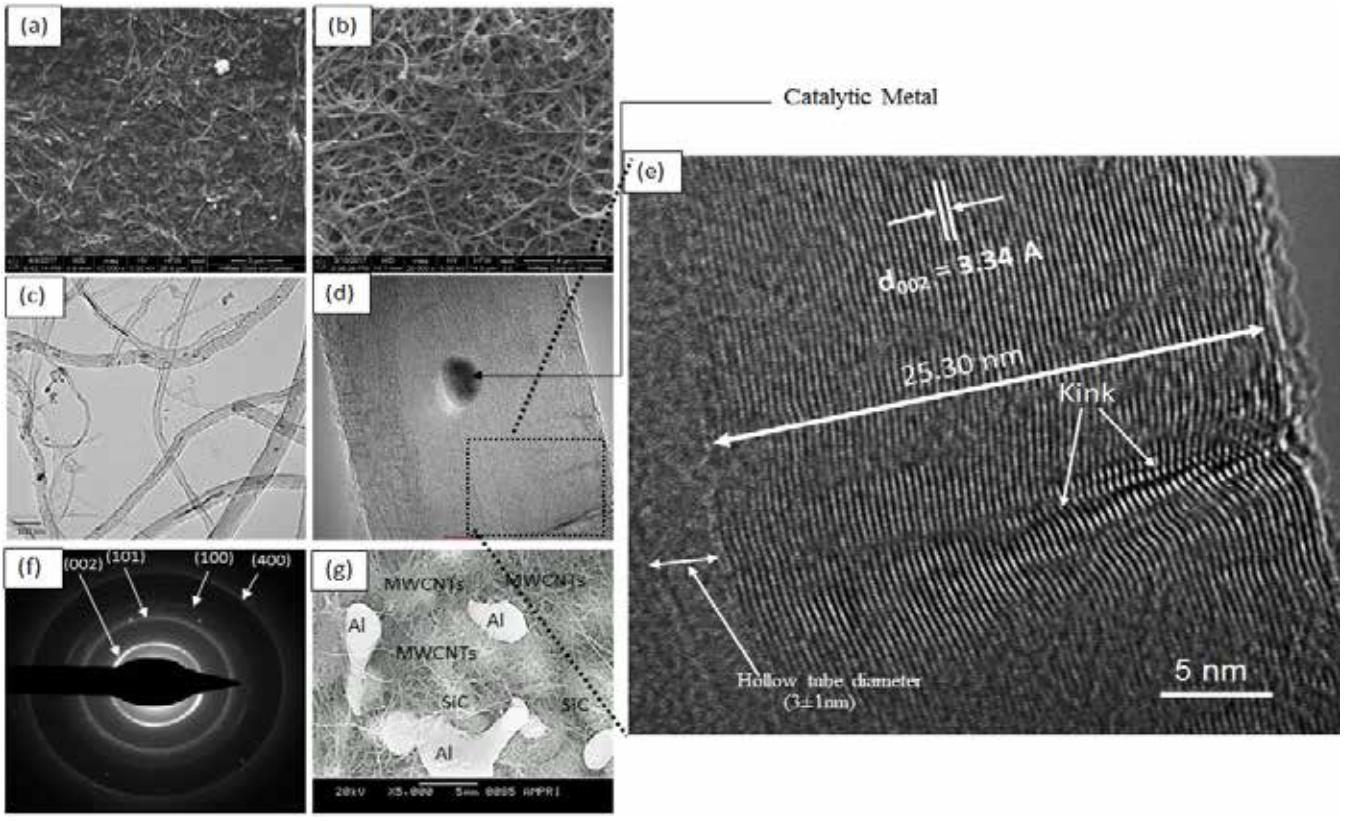
Pressure die cast and squeeze cast composite
Yield strength: 170 to 220 MPa; UTS: 200 to 280 MPa



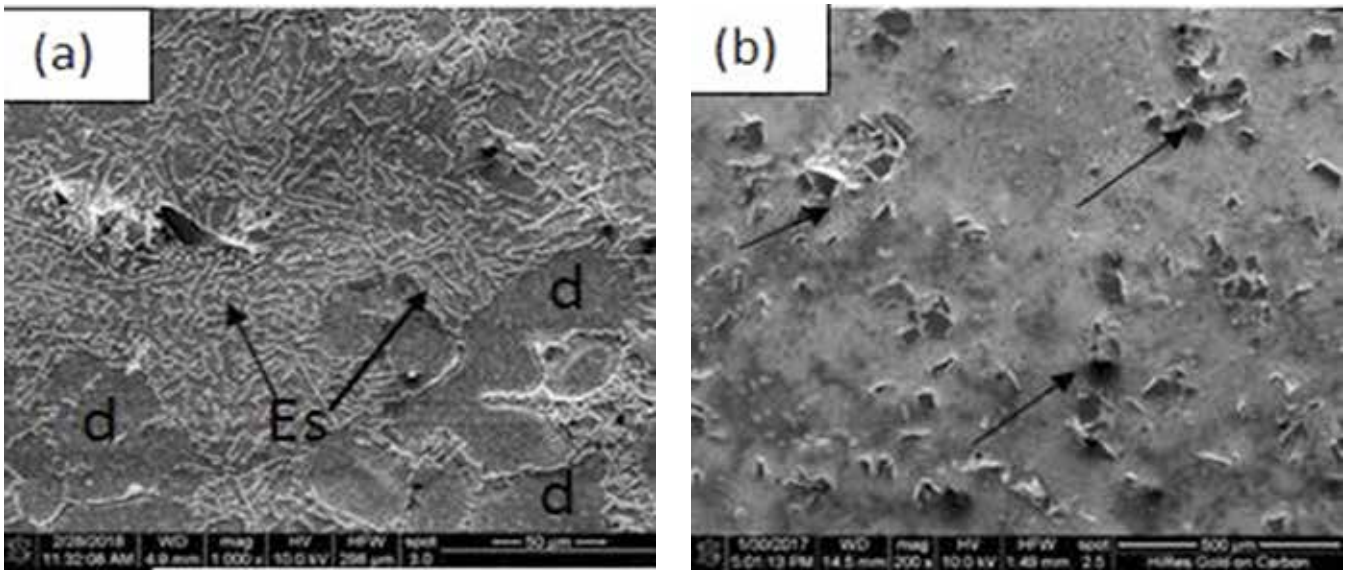


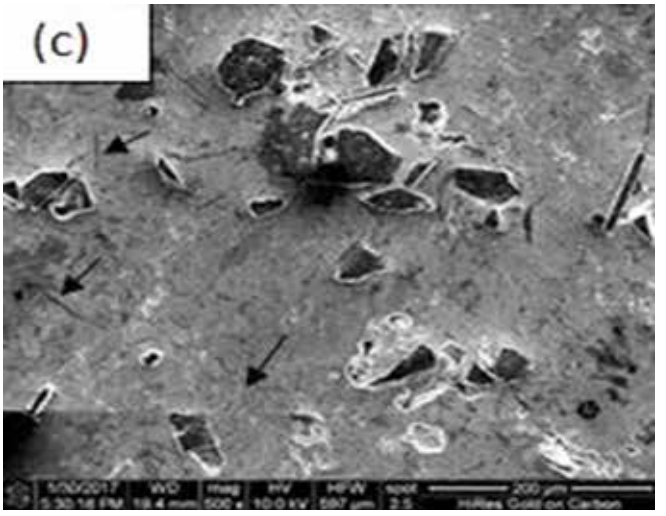


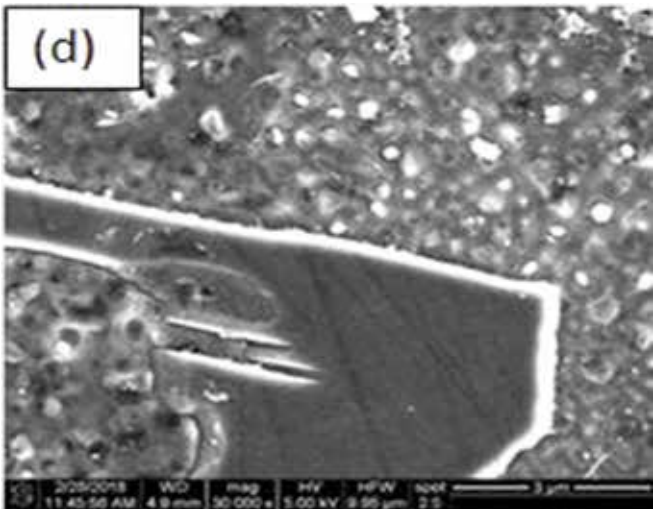
FUNCTIONALISATION OF CNTS, PARTICLE PROCESSING



NANO COMPOSITE AND HYBRID COMPOSITE




(c)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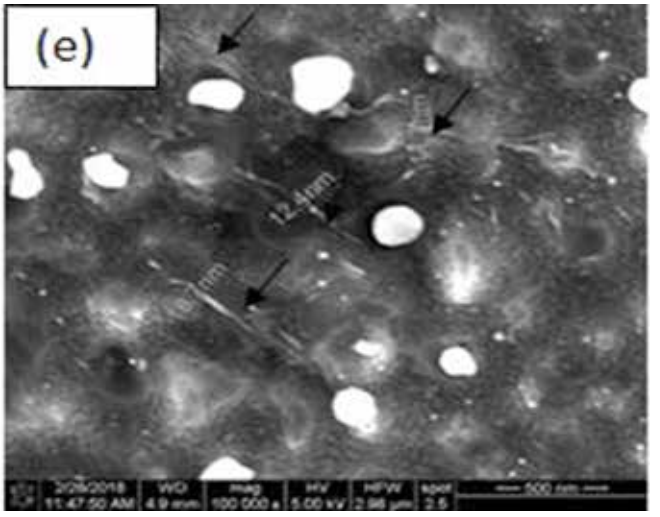
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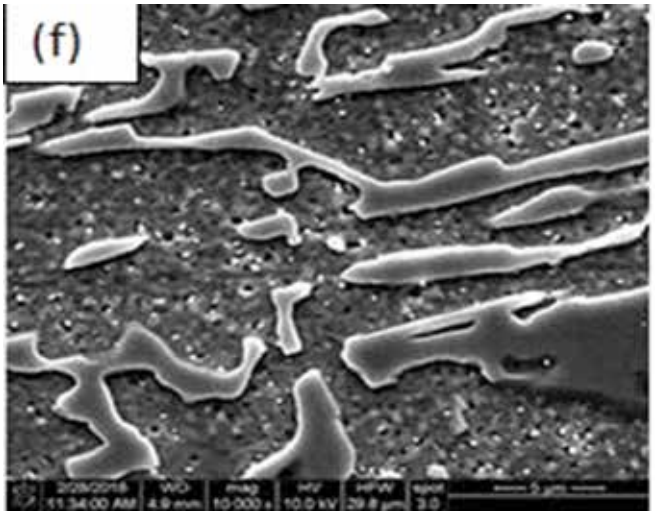
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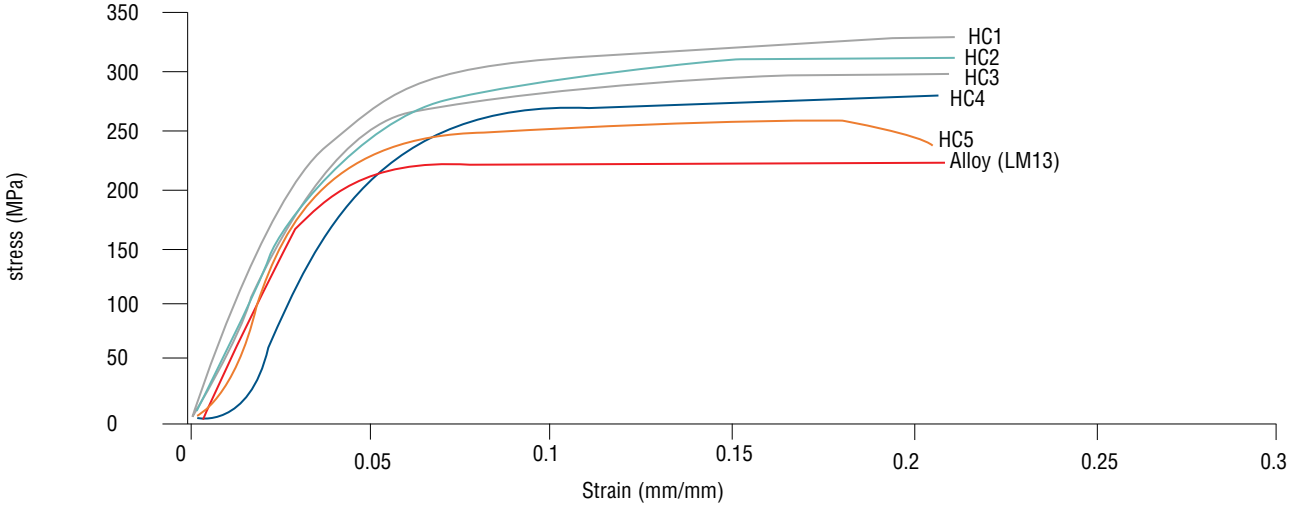
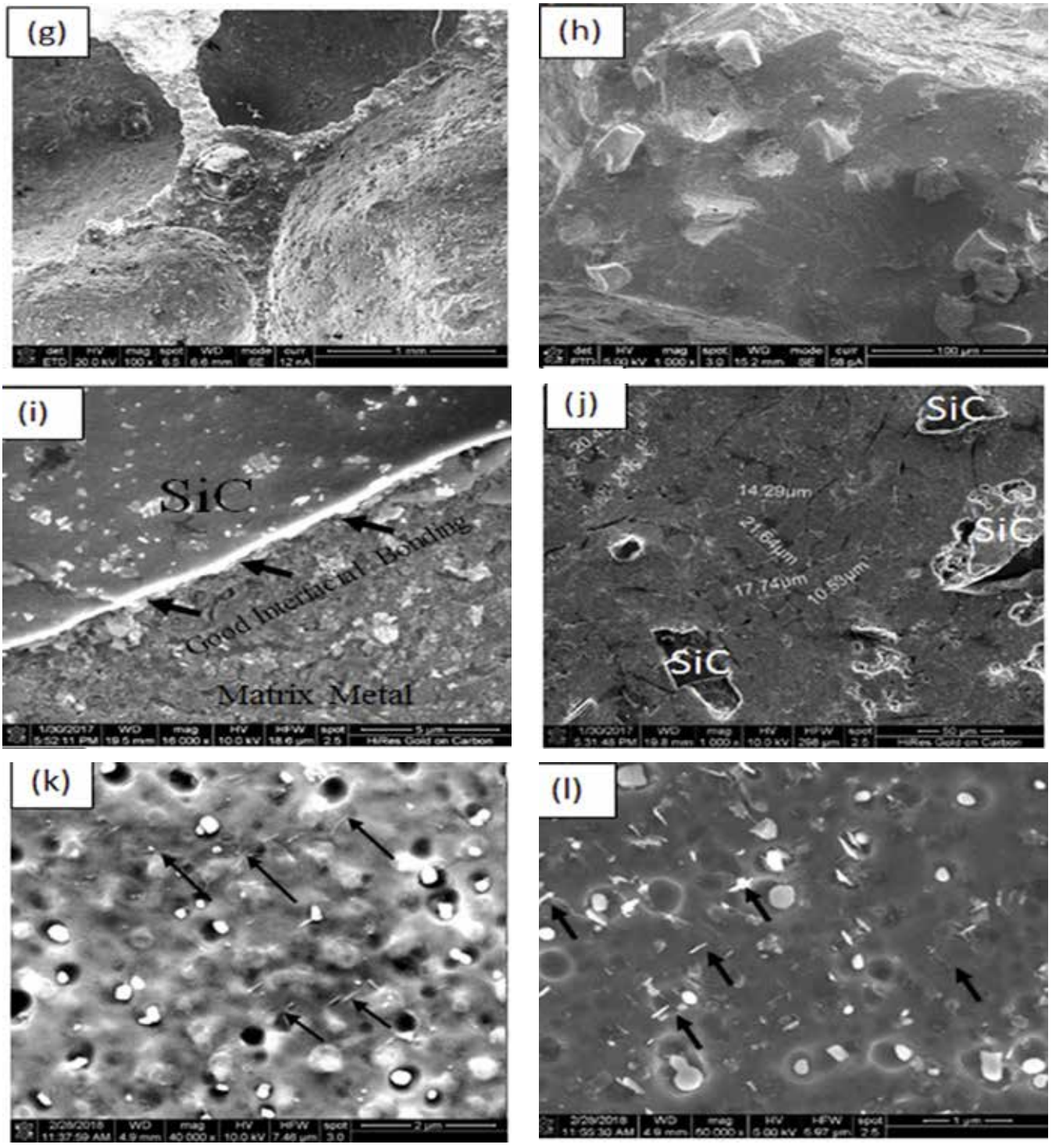
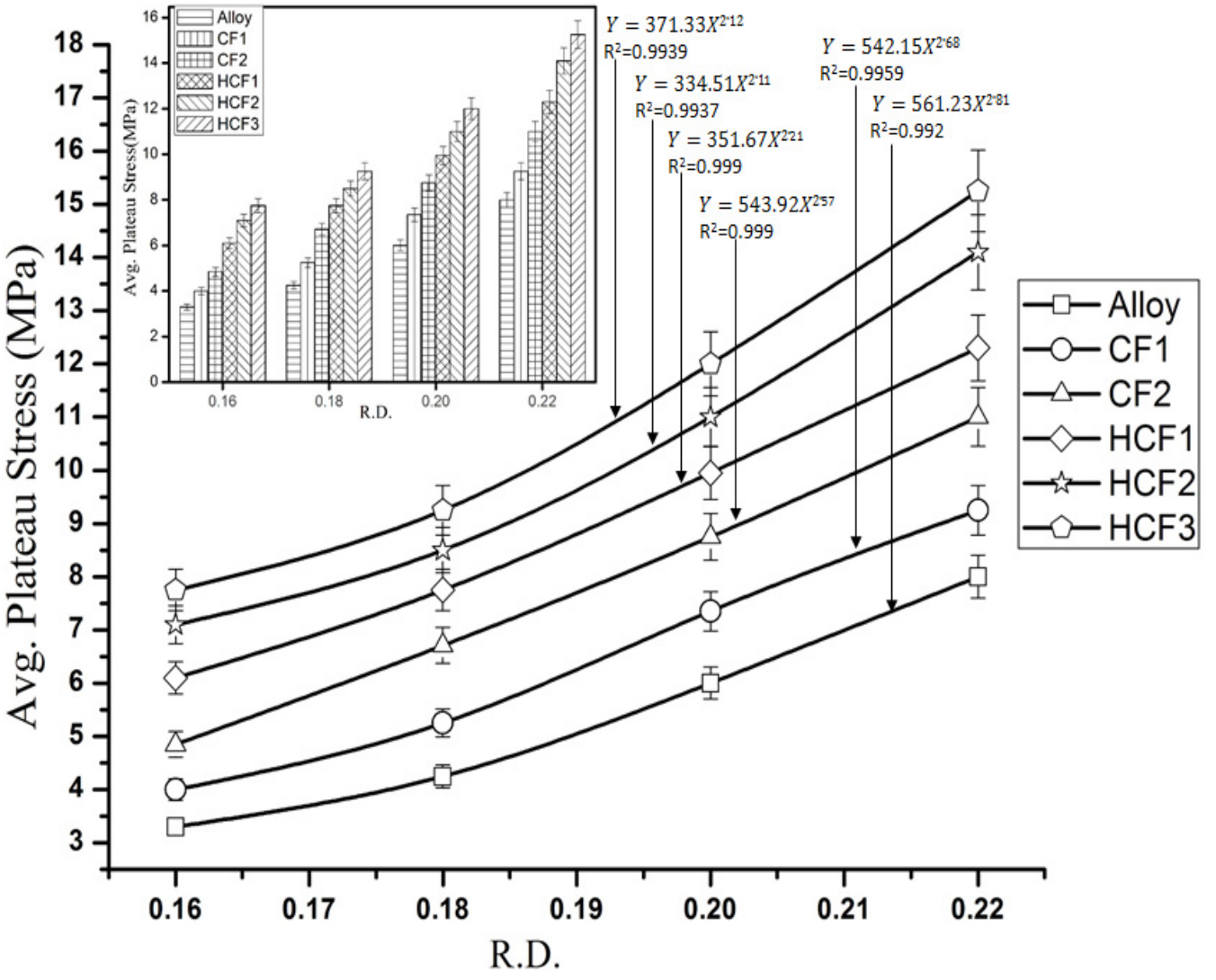

stress (MPa)
350
300
250
200
150
100
50
0
0
0.05
0.1
0.15
0.2
0.25
0.3
Strain (mm/mm)
HC1
HC2
HC3
HC4
HC5
Alloy (LM13)

MICROSTRUCTURE AND MECHANICAL PROPERTIES OF HYBRID FOAM





METAL FOAMS AND MMCS AT CSIR-AMPRI

Aluminium metal matrix composites
(Stir casting & in-situ technology, 60 kg/heat)
Technology developed and licensed
Strength: 200 to 450 MPa (cast, rolled/forged)

Density – 1/3rd of steel
Automobile, Defence, Aerospace and
General Engineering

Connecting rod

Nose Cone

Break drum

METAL FOAMS AND MMCS AT CSIR-AMPRI

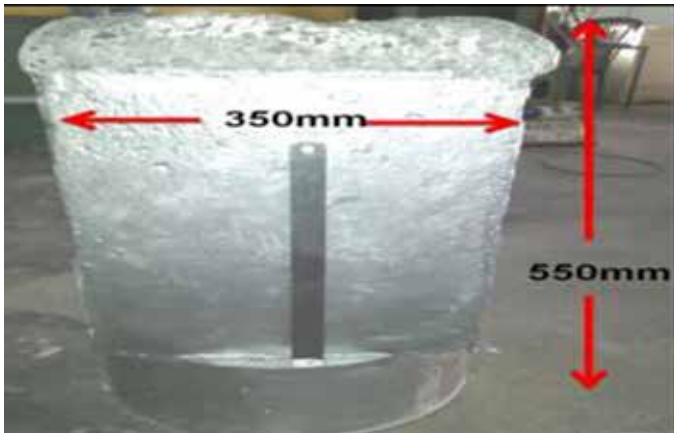
Closed cell Al-foams (100 kg/day)

- Density: 0.2 to 0.8 g/cm3
- Porosity: 40 to 90 percent; Strength: 2 to 35 MPa
- Sound absorption: Equivalent to glass wool

– Auto industries: Crash-worthiness, weight reduction, sound and vibration control
– Defence: Blast resistance, armour
– Rail and ship building: Flooring, cabins & hulls

crash box and bumber

Blast resistant panel, foam (30 kg) & structure



METAL FOAMS AND MMCS AT CSIR-AMPRI

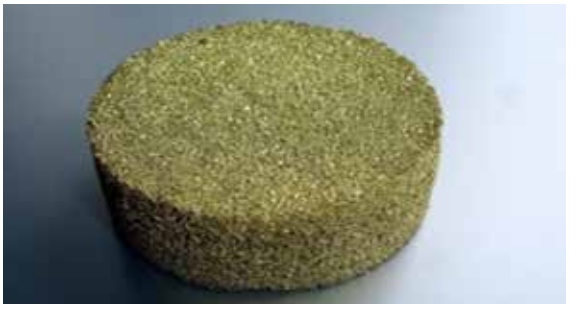
Open Cell Foams (Porosity: 50 to 90%)

- Nickel , Copper, Carbon and Titanium
- Aluminum, Titanium, Stainless steel
- Process developed. Animal trials made with Ti-foam

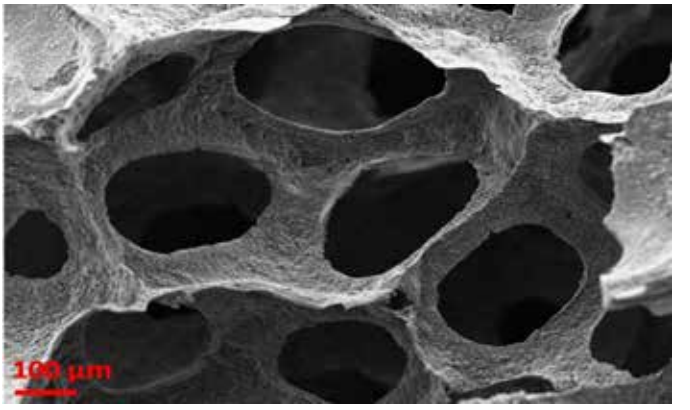
Bio medical applications

- Filters , Heat Sink, Catalyst, Batteries
- Capacitors, EMI shielding

Ti-foam (bone scaffold and joining applications)



Carbon-foam/energy storage and Ni-foam/high temperature applications



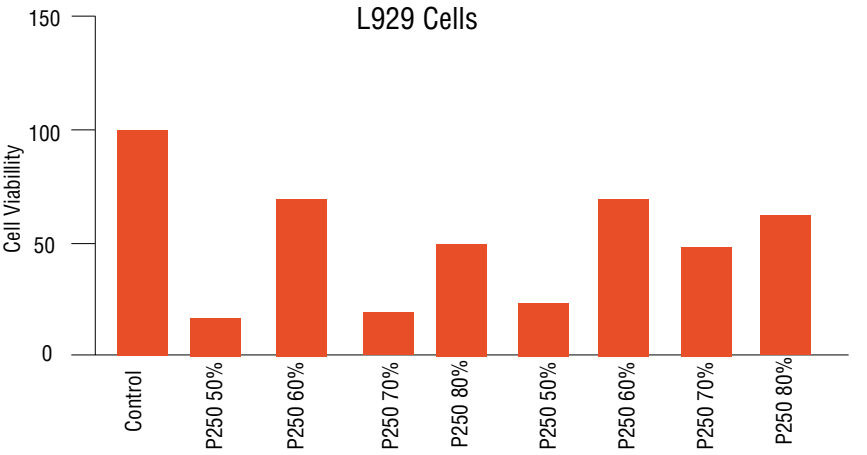
TI-FOAMS FOR FILTERS AND PROTOTYPE BIO-IMPLANTS AT CSIR-AMPRI

• Partially open cell Ti-foam with precise control of cell size and pore fraction could be made

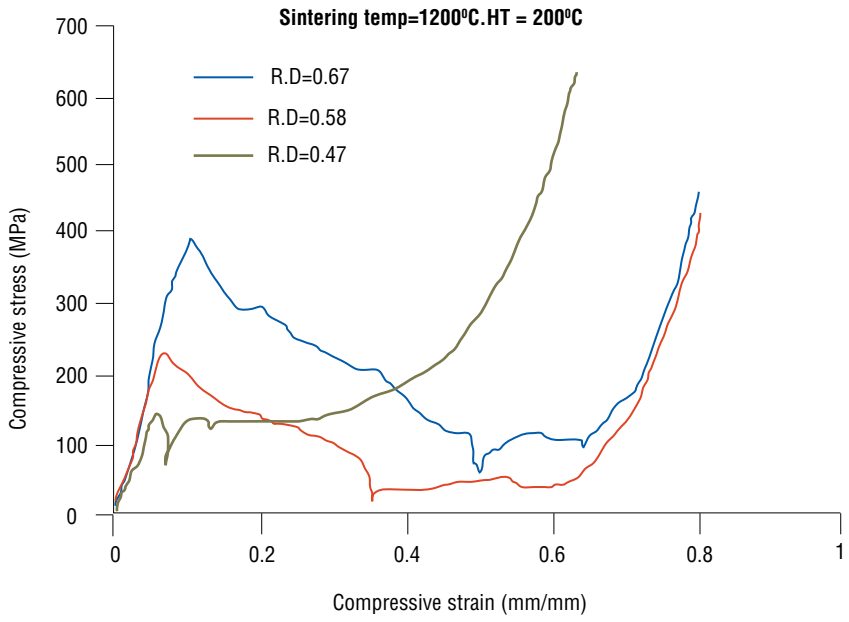
• These could be coated with HAP solution for improved bio-compatibility

• The powder metallurgy technology for Ti-foam is developed at CSIR-AMPRI

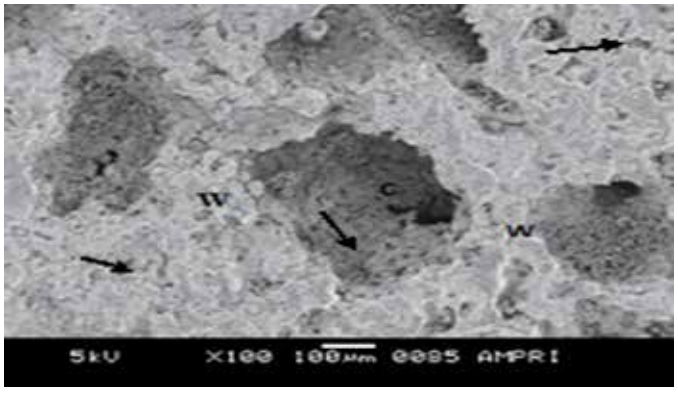
• Because of porous and bioactive coating, these implants help faster cell growth and adherence vis-à-vis faster recovery and increased life

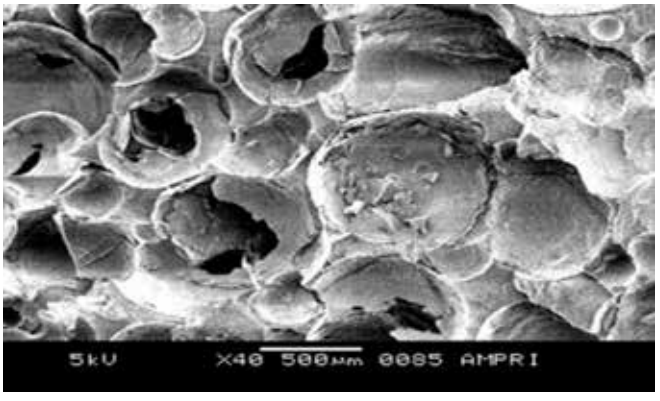


Stress-strain curves



Ti-foam lumber fusion





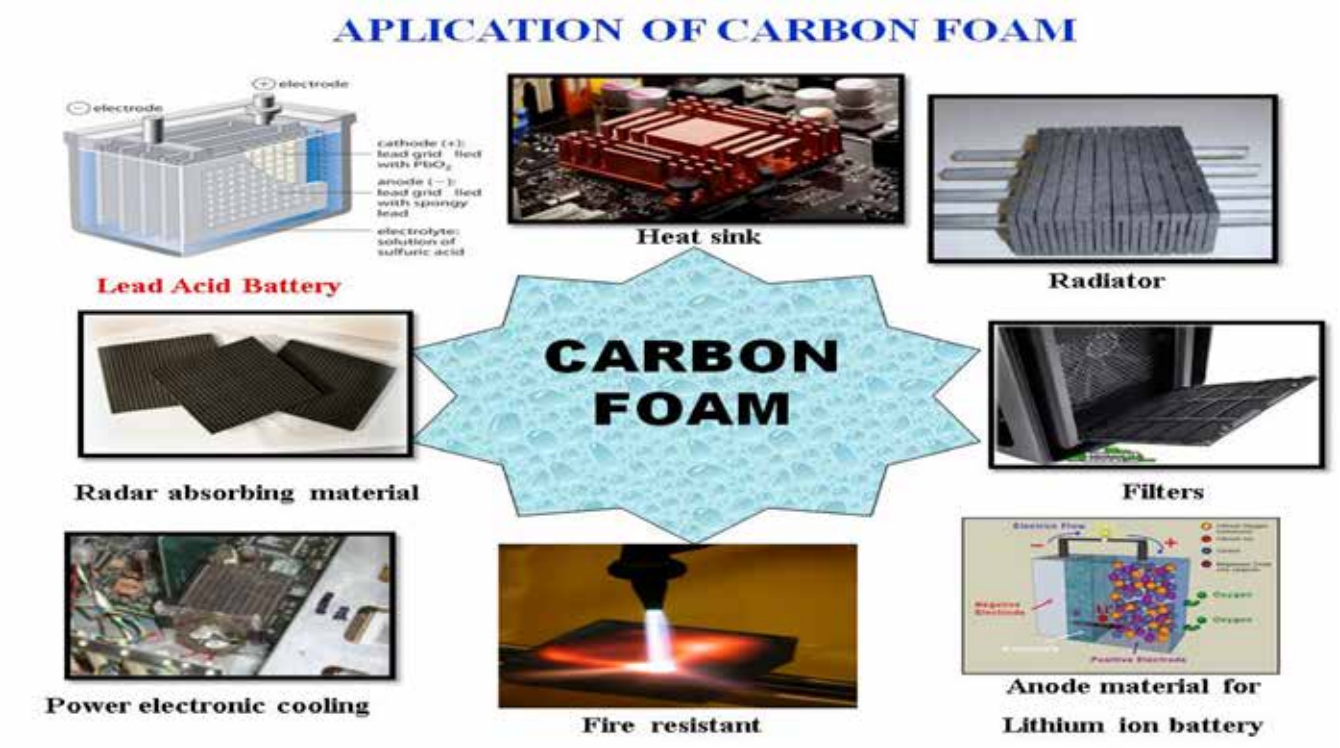
Foam filter

Microstructure of Ti-foam

CARBON FOAM AND ITS APPLICATIONS AT CSIR-AMPRI

- Porous solid
- Light-weight
- Low density (>0.5 g/cc)
- Thermal expansion is very low
- High thermal conductivity (>100 W/m.K)
- High temp tolerance (up to 3000°C, inert atm)
- Large surface area with open cell structures
- Porosity (70-80 percent)

Properties	Carbon foam
Density (g/cm3)	< 0.50
Compressive strength (MPa)	5-8
Electrical conductivity (S/cm)	80-150
Thermal conductivity (W/m.K)	>60
Total EMI shielding (dB)	>80
Open porosity (%)	75-80



Photographic and SEM image of carbon foam