

# Processed Text

compositestructures92 2010 2793 2810 contentslistsavailableatsciencedirect composite structure journal homepage www elsevier com locate compstruct review review recent research mechanic multifunctional composite material structure ronald f gibson departmentofmechanicalengineering universityofnevada reno m 312 reno nv89557 unitedstates r c l e n f b r c articlehistory inresponsetothemarkedincreaseinresearchactivityandpublicationsinmultifunctionalmaterialsand availableonline8may2010 structuresinthelastfewyears thisarticleisanattempttoidentifythetopicsthataremostrelevantto multifunctionalcompositematerialsandstructuresandreviewrepresentativejournalpublicationsthat keywords arerelatedtothosetopics articlescoveringdevelopmentsinbothmultiplestructuralfunctionsandinte multifunctional gratedstructuralandnon structuralfunctionssince2000areemphasized structuralfunctionsinclude material mechanical property like strength stiffness fracture toughness damping non structural structure functionsincludeelectricaland orthermalconductivity sensingandactuation energyharvesting stor composite age self healingcapability electromagneticinterference emi shielding recyclabilityandbiodegradabil nanocomposite ity many recent development associated polymeric composite material polymer corresponding advance nanomaterials nanostructures many article reviewed thearticleconcludeswithadiscussionofrecentapplicationsofmultifunctionalmaterialsandstructures suchasmorphingaircraftwings structurallyintegratedelectroniccomponents biomedicalnanoparticles fordispensingdrugsanddiagnostics andopticallytransparentimpactabsorbingstructures severalsug gestionsregardingfutureresearchneedsarealsopresented cid 2 2010elsevierltd allrightsreserved content 1 introduction 2793 2 multiplestructuralfunctions 2795 2 1 compositestructuralmaterials 2795 2 2 hybridmultiscalestructuralcompositematerials 2795 3 integratedstructuralandnon structuralfunctions 2797 3 1 electricaland orthermalconductivity 2797 3 2 sensingandactuation 2799 3 3 energyharvesting storage 2801 3 4 self healingcapability 2803 3 5 electromagneticinterference emi shielding 2804 3 6 recyclabilityandbiodegradability 2805 4 recentapplicationsofmultifunctionalmaterialsandstructures 2805 5 concludingremarks 2807 acknowledgement 2807 reference 2808 1 introduction creased markedly recent year fig 1 show number english language refereed journal article multifunctional thenumberofpublicationsdealingwithvariousaspectsofthe materialsandstructureshassteadilyincreasedsince2000 based mechanic multifunctional material structure ondatacollectedfromtheengineeringvillage cid 2 web basedinfor mationservice alongwiththeincreaseinthenumberofpublicationsinthisareacomesaneedforacomprehensivereviewarticle e mailaddress ronaldgibson unr edu 0263 8223 seefrontmatter cid 2 2010elsevierltd allrightsreserved doi 10 1016 j compstruct 2010 05 0032794 r f gibson compositestructures92 2010 2793 2810 nomenclature surfaceareaofsphericalparticle se emishieldingeffectiveness c dragcoefficient flightendurancetime e c liftcoefficient u electrical dielectric energydensity l e e nominalstoredbatteryenergy v volumeofsphericalparticle b e incidentelectricfield w battery subsystemweight b e transmittedelectricfield w payloadsubsystemweight pl h incidentmagneticfield w propulsionsubsystemweight pr h transmittedelectricfield w structuresubsystemweight k piezoelectriccouplingcoefficientforsensing w mechanical strain energydensity k piezoelectriccouplingcoefficientforactuation conductivityexponent k electricalconductivityofcomposite g crackhealingefficiency c k electricalorthermalconductivityoffiller g efficiencyfactorforbattery f b k electricalorthermalconductivityofmatrix g propellerefficiency p k modeifracture toughnessforhealedspecimen q airdensity ichealed k modeifracture toughnessforvirgin specimen u concentrationofcarbonnanotubes icvirgin p critical fracture load healed mode fracture speci u critical concentration carbon nanotube percola chealed c men tionthreshold p criticalfractureloadforvirginmodeifracturespecimen cvirgin wingplanformarea andtheobjectiveofthispaperistoaddressthisneed theempha type b wouldbeaload bearingstructurethathasthecapability sisofthepublicationssurveyedwillbeonthemechanicsaspects ofprovidingitsownnoiseandvibrationcontrol self repair ther

although the multidisciplinary nature of the topic will lead to the malinsulation and energy harvesting storage  
 whereas an examination of a publication relevant discipline type c would structure combining function  
 material science thermodynamics electronics addition type type b recent development  
 the vast majority of the surveyed articles deal with polymer composites definition multifunctional material must  
 multifunctional material necessarily composite material composite due large number article involved  
 strong growth in use composites has greatly lack electronic access many conference proceeding  
 influenced by multifunctional design requirements the traditional  
 emphasis of this review is on the more accessible refereed journal  
 approach to the development of structures is to address the load article  
 it was not practical to cover all of these articles and since carrying function functional requirement separately  
 some articles had already been covered by previous related review resulting suboptimal load bearing  
 structure add article attempt made select representative article attachment perform non structural  
 function each of the relevant categories according to fig 1 most of the relevant penalty of added weight recently  
 however there has been in event articles have been published since 2000 so that is the focus  
 created interest in the development of load bearing materials and of this review  
 structures which have integral non load bearing functions guided increased interest multifunctional  
 material structural recent discovery multifunctional biological systems  
 is driven by the need for the development of new materials and structures  
 and structures that simultaneously perform multiple structural  
 due to the interdisciplinary nature of multifunctional materials function b combined non  
 structural and structural functions and structures and the need to avoid duplication in the current review c one  
 example multifunctional structure type view it is appropriate to cite several relevant previous review articles  
 would be a composite structure that has high strength high stiffness for example baur and silverman 1  
 reviewed the challenges high fracture toughness high damping example opportunity multifunctional  
 nanocomposite aerospace structure while ye et al 2 reviewed developments in the application artificial  
 intelligence functionalize composite air frame definition multifunctional material must composite  
 becoming increasingly apparent nano structured composites can produce and enhance multifunctional  
 ability in ways that conventional composites could not for example thostenson et al 3 and chou et al 4  
 reviewed recent advances related science technology carbon nanotube their composites  
 breuer and sundararaj 5 reviewed recent studies on polymer carbon nanotube composites li et al 6 surveyed  
 recent advance related use carbon nanotube their composites as sensors and actuators while gibson et al 7  
 reviewed recent publication dealing vibration carbon nanotubes and their composites and sun et al 8  
 reviewed articles dealing with various types of energy absorption in nanocomposites addition small amount  
 carbon nanotube non conducting polymer polymer composite fig 1  
 recent english language refereed journal publications related to multifunctional  
 can be transformed to conducting materials thus enhancing their functional material structure data collected  
 engineering village cid 2 web based information service multifunctionality accordingly  
 bauhofer and kovacs 9 have reviewed gibson composite structures 92 2010 2793 2810 2795  
 viewed relevant research on electrical percolation in carbon nano tube polymer composite modeling  
 analysis functionally graded materials fgm have been reviewed by birman and byrd 10  
 the field of structural health monitoring shm is highly relevant several review article appeared recently  
 montalvo et al 11 reviewed vibration based shm of composite material similar review emphasis composite  
 delamination identification published earlier zou et al 12 recent developments in self  
 healing polymeric materials were reviewed by wu et al 13 articles on energy harvesting  
 for sensor networks in shm were reviewed by park et al 14 piezoelectric material often utilized energy  
 harvesting publication topic reviewed sodano et al 15 anton and sodano 16 and cook chennault et al 17  
 closely related shm study shape memory polymer smp  
 and reviews of recent advances in smp have been published by ratna and karger kocsis 18 gibson et al 19  
 edited the proceedings 2008 summer fall technical conference entitled multifunctional materials  
 working smarter together lau et al 20 archived selected paper 2008 international fig 2  
 loss modulus for pure pc and several swnt pc nanocomposites at different conference multifunctional material  
 structure mfms strain level reprinted permission 22 copyright 2005 american institute of physics 08

which was held in Hong Kong thermal expansion CTE 27 desirable change 2 multiple structural functions  
 volume fraction silica increased much strength will start to drop due to particle agglomeration poor par 2 1  
 composite structural materials tied dispersion and reduced silica epoxy interfacial strength even composite  
 always possible simultaneously in among important structural function system proves several properties  
 in some cases modification to composite can provide a stiffness strength fracture toughness ductility fa  
 ites lead to major improvements in some properties while causing a strength energy absorption damping  
 and thermal stability minor reductions in other properties for example the incorporation although structural  
 weight function extremely thin rubber microparticles epoxy matrix glass fiber  
 important design consideration which has driven more design to reinforced epoxy composite improved  
 tensile fatigue life towards lightweight composite materials in recent years with con  
 the composite by a factor of three while causing only a 5 2 reduction in structural material difficult achieve  
 tion tensile strength 12 7 reduction elastic simultaneous improvement multiple structural function  
 modulus 28 the increasing use of composite material has been driven in part  
 by the potential for such improvements for example it has been 2 2  
 hybrid multiscale structural composite materials shown simultaneous improvement vibration damping  
 and fracture toughness in composite laminates are made possible increasing report literature significant  
 incorporating polymeric interleaf composite improvement multiple structural function achieved lamina  
 21 however true interleaf thickness new hybrid multiscale composite incorporate nano  
 is less than a critical value further increases in interleaf thickness scale reinforcement well conventional  
 micron scale fiber cause the fracture toughness to drop off while the damping keeps particle reinforcement  
 example fiber dominated increasing property E longitudinal tensile strength and elastic modulus  
 the use of nano reinforcements in polymer composites has provided conventional unidirectional polymer  
 composite micron reduced unprecedented improvement mechanical property size fiber reinforcement  
 excellent corresponding the composite's K<sub>ratkare</sub> et al 22 measured greater than 1000 matrix dominated  
 transverse tensile strength longitudinal increase fig 2 in the loss modulus of polycarbonate PC without  
 compressive strength property often poor however  
 significant reductions in the storage modulus when the PC was en  
 traditionally poor properties can be significantly improved by hanced 2wt single walled carbon nanotube  
 SWNTs replacing the neat resin in polymer matrix with a nanocomposite ma  
 was hypothesized that frictional sliding at the SWNT/PC interfaces trix see fig 3 Vlasveld et al 29 b growing  
 was the reason for the enhanced energy dissipation this hypothe  
 nano reinforcements like carbon nanotubes on the surface of the fi sis is supported by the analysis of Zhou et al 23  
 who developed a model frictional sliding damping mechanism based on  
 example approach Uddin Sun 31 reported interfacial stick slip frictional motion nanotube silica  
 nanoparticle enhanced epoxy used and the polymer matrix Rajoria and Jalili 24 reported that mul matrix  
 material unidirectional E glass epoxy composite Ti walled carbon nanotube MWNTs effective  
 longitudinal compressive strength and modulus were both signifi SWNTs in improving damping of epoxy  
 but there was no signifi cantly improved minimization particle agglomeration can't effect storage modulus  
 another way incorporate resulting improved dispersion of silicate nanoparticles in the epoxy improved  
 damping associated nanotube reinforcement matrix due use sol gel process based use is to embed nano  
 enhanced polymer film sub layers within a mul organosilicate sol colloidal silica organic solvent believed  
 to be functional composite laminate 25 26 be the primary reason for the improvements more recent research  
 by mixing silica microparticles and epoxy in the right propor the same author extended the approach to hybrid  
 multiscale tions it is possible to simultaneously increase strength and modu composite containing silica  
 nanoparticles lu resulting composite reducing coefficient sol gel process alumina nanoparticles carbon  
 nanofibers 2796 r f Gibson composite structures 92 2010 2793 2810 fig 5  
 flexural modulus of different nanocomposites at various particle loadings reprinted from 32  
 with permission from Elsevier fig 3 nanoparticle reinforcement of the matrix in a unidirectional fiber composite  
 reprinted from 29 with permission from Elsevier fig 6  
 flexural strength of different nanocomposites at various particle loadings reprinted from 32  
 with permission from Elsevier fig 4 multi walled carbon nanotube grown surface carbon fiber  
 reprinted from 30 with permission from Elsevier CNF in an epoxy matrix 32 as shown in figs 5 7 simultaneous  
 improvement least 30 modulus strength strain

break are possible with several types of these hybrid nanocomposites similarly Liu et al 33 Zhang et al 34 found young modulus tensile strength and fracture toughness of epoxy simultaneously improved addition sol gel formed nanosilica particle dispersion particle excellent Manjunatha et al 35 observed addition 10 wt sol gel formed nanosilica to the epoxy matrix resulted in simultaneous improvement 44 tensile strength 74 tensile modulus and a factor of 2.3 in tensile fatigue life of a glass fabric reinforced epoxy composite the presence of the nanoparticle Fig 7 flexural strain break different nanocomposites various particle sizes was believed to suppress matrix cracking and reduce delamination loading reprinted from 32 with permission from Elsevier

nation growth rate thus improving fatigue life since hybrid multiscale composite typically have reinforcement size ranging decreasing particle size micron and nano range long micron scale nano scale essential as particle agglomeration was avoided Cho and Sun 37 later used stand the effect of particle size on the resulting composite proper molecular dynamic simulation to show that if the polymer nano tie important observations regarding such effects were reported particle interaction strength is greater than the polymer polymer by Cho et al 36

where measured modulus and strength of vinyls interaction strength the polymer density near the polymer nanopolymer matrix composites containing spherical alumina particle particle interface and the young modulus of the nanocomposite or glass beads with particle sizes ranging from 0.5  $\mu\text{m}$  down increase significantly reduced particle size to 15 nm it was found that the young modulus was not affected search needed particle size effect structural varying particle size micron range particle and non structural properties of nanocomposites and hybrid modulus was reduced in the nano range the young modulus increased in scale composites this is particularly true for analytical modeling with decreasing particle size tensile strength increased since most of the publications to date involve experimental work R. F. Gibson composite structures 92 2010 2793 2810 2797 Fig 8

use of aligned CNT forests to strengthen the interlaminar region in composite laminates reprinted from 41 with permission from Elsevier

approach b involves growth nanotube important non structural function including electrical surfaces of micron sized fibers has also been the subject of numerous thermal conductivity sensing actuation energy harvesting our investigation Thostenson et al 38 grew carbon nanotubes storage self healing capability electromagnetic interference CNTs on the surface of carbon fibers using chemical vapor deposition shielding recyclability and biodegradability sition CVD then conducted single fiber fragmentation tests of the modified carbon fibers in an epoxy matrix to determine the fiber 3.1 electrical and thermal conductivity matrix interfacial shear strength it was found that the interfacial shear strength of the modified carbon fibers was 15 greater than among important non structural function that of the baseline carbon fibers Veedy et al 39 also used CVD to structure may need electrical thermal conductivity grow aligned CNT forests perpendicular to the surface of 2D woven the most widely used composites have polymer matrix materials sic fabric cloth consisting micron size sic fiber fabric which are typically poor conductors one very important application infiltrated epoxy resin stacked form 3D woven polymer composite electrical conductivity composite compared baseline composite 3D woven required aircraft structure non conducting structure

posite was found to exhibit simultaneous and significant improve may damaged lightning strike conductive polymer matrix in the model and model II fracture toughnesses the flexural nanocomposites investigated possible replacement modulus the flexural strength the flexural toughness coefficient non conducting polymer matrix material would eliminate of thermal expansion the thermal conductivity and the electrical need for add on metallic conductors which are too heavy trical conductivity true multifunctional composite and may be difficult to repair 45 enhanced thermal conductivity combining structural and non structural functions and will be a composite important cooling electronic circuit discussed further in the next section further studies and applications propulsion systems

the structural advantages of nanocomposites of aligned CNT forests to conventional fiber composites have been have already been summarized in the previous section and there reported Wardle colleague 40 44 focused abundant evidence literature simultaneous improve the use of the aligned CNT forests to improve interlaminar strength matrix mechanical electrical properties nanocomposites and toughness these are major concerns about conventional composites 46 49

posite laminates because of the weak matrix resin rich region that

it turns out that very small concentrations of carbon nanotubes exist between the composite laminae as shown in fig 8 vertically conducting nanoreinforcements polymers lead to dis aligned cnt forests can bridge and strengthen this interlaminar region proportionately large improvements in the electrical conductivity are obtained specifically author reported cnt of the nanocomposite for example fig 10 shows that the electrical conductivity modified interface increased mode interlaminar fracture toughness of cnt epoxy nanocomposites increases by nearly a factor of 6 decades when the cnt concentration is increased by only 2 wt% corresponding mode ii value factor 3 above the percolation threshold which is the cnt concentration analytical modeling fracture toughness cnt modified transition in the polymer that characterizes the insulator conductor transition 0.04 wt% case percolation theory accurately was reported later in 43 these so called fuzzy fiber cnts grown rapidly describe this transition by equation on carbon fibers concept applied to composite laminates can provide a quantitative prediction of interlaminar intralaminar reinforcement illustrated in fig 9 44 sandler et al 50 reported ultra low percolation thresholds as low as 0.0025 wt% aligned mwnt epoxy nanocomposites 3 integrated structural and non structural functions percolation threshold cnts polymer matrix material is so low because the extremely high aspect ratios of cnts make indicated previous section development relatively easy for contiguous conducting path percolation nanocomposites and hybrid multiscale composites containing both network to form along the tangled cnts in the insulating polymer conventional micron level reinforcement nano level reinforcement matrix fig 11 from li et al 51 show show the percolation threshold for composites has made it possible to achieve simultaneous improvement in decrease increasing cnt aspect ratio since processing multiple structural function multiple typically breaks up cnts into shorter lengths it is important to design non structural function well section focus several development processes which preserve the high aspect ratios of cnts thus 2798 r f gibson composite structures 92 2010 2793 2810 fig 9 illustration of fuzzy fiber reinforced plastic for radially aligned cnts grown on advanced fiber cloth b cnt intralaminar and interlaminar reinforcement reprinted from 44 with permission from Elsevier fig 11 effect of cnt aspect ratio on percolation threshold for cnt nanocomposites varying dispersion state copyright wiley vch verlag gmbh co kgaa reproduced from 51 with permission the cnts are straight the importance of waviness was confirmed fig 10 electrical conductivity cnt epoxy nanocomposites various cnt li et al 53 who used monte carlo simulation to show that concentration percolation threshold 0.04 wt% reprinted 9 the electrical conductivity of composites with wavy nanotubes permission from Elsevier less than that of composites with straight nanotubes ensuring the desired low percolation thresholds thostenson et al although thermal conductivity cnt polymer nanocom 52 reported that a 3 roll mill process induces intense shear in composites increase increasing cnt concentration in a cnt vinyl ester nanocomposite while preserving the high aspect ratio gradual sharp insulator conductor aspect ratio cnts photomicrograph show cnts transition percolation threshold electrical conductivity wavy but most analytical models are based on the assumption that 54 according to shenogina et al 54 the difference lies in the r f gibson composite structures 92 2010 2793 2810 2799 conductivity ratio  $k/k_0$  for thermal transport even for very conductive and the corresponding piezoelectric coupling coefficient for conversion of ductive high aspect ratio cnts  $k/k_0$  is only about 104 but for electrical energy to mechanical energy for actuation for thermal transport  $k/k_0$  is much higher 1012 1016 result of electrical energy to mechanical energy electrical transport is dominated by the percolating cnt network  $k/k_0 \propto w^{1/4}$  whereas thermal transport strongly influenced polymer matrix although there is a lack of a percolation threshold for the most widely used forms of piezoelectric materials are wavy mal conductivity cnt polymer composite small amounts 61 and thin films 62 and numerous publications have dealt with cnts still lead to disproportionate increases in composite thermal conductivity with time over many years piezoelectric microelectromechanical conductivity example biereuk et al 55 found 1 wt% system membrane for sensing and actuation have been the subject of swnt in epoxy resulted in a 125% increase in thermal conductivity extensive research state of the art area room temperature bonnet et al 56 measured 55 very recently reviewed by tadigadapa and mateti 63 so in order to increase thermal conductivity 7 wt% swnt in pmma can avoid duplication focus important recent positive and kim et al 57 reported a 57

increase in thermal conductivity development structurally integrated sensing actuation ductility adding 7 wt % MWNTs phenolic resin however load bearing multifunctional composite structures since higher filler loading required create significant although not as common as piezoelectric wafers or thin films improvements in thermal conductivity of polymers this may lead piezoelectric fiber investigated possible active top processing issues for example Ganguli et al. 58 were able to component multifunctional fiber reinforced composite achieve a 28 fold increase in thermal conductivity of epoxy by adding earliest reports of piezoelectric fiber composites PFC were appearing 20 wt % chemically functionalized exfoliated graphite entirely published by Hagood and Bent 64 and Bent et al. 65 flake but graphite loading levels greater than 4 wt % were found embedded micron sized piezoelectric fibers in an epoxy matrix to increase the viscosity of the mixture beyond the desirable processing window vacuum assisted resin transfer molding dielectric mismatch the PFC laminate was built up from PFC laminate process application small amount in an embedded between conventional graphite epoxy laminate and CNTs are needed to produce acceptable thermal conductivity interlaminar electrode applied electric field required example Si H et al. 59 found that the through thickness thermal actuation good agreement obtained measured conductivity of epoxy adhesive joints can be increased by several electrically induced deformations and those predicted by a modified orders of magnitude when aligned MWNT nanograft is incorporated classical lamination theory which included actuator induced rated in the epoxy adhesive fig 12 stress terms 65 more recently developed hollow piezoelectric fibers 66 67 offer the advantage of lower operating voltage and a 3 2 sensing and actuation broader choice possible matrix material compared solid cross section piezoelectric fiber Brei Cannon 67 investigating sensing actuation two closely related non structural gated the hollow piezoelectric fiber concept in fig 13 with emphasis function and in many cases the same material or device can be used for both effect three key design parameter matrix fiber used for both functions as well as for other functions like energy storage modulus ratio aspect ratio individual fiber harvesting storage structural health monitoring several overall active composite volume fraction performance cent review article already covered much recent manufacturing and reliability of the active composites in fig 13 search related sensor actuator used actuation mode radial poling piezoelectric fiber multifunctional structure example Li et al. 6 Gibson Sults in longitudinal deformation of the fiber while in the sensing et al. 7 reviewed recent research related sensor mode longitudinal deformation results in radial electrical output actuators based on carbon nanotubes and their composites still more recently Lin and Sodano 68 69 developed piezoelectric view article by Ratna and Karger Kocsis 18 covers recent research structural fibers consisting of conductive structural fibers such as on shape memory polymers which have potential applications as sensors and actuators piezoelectric materials such as lead zirconate titanate PZT polyvinylidene fluoride PVDF aluminum nitride AlN can be embedded in structures for sensing and actuation as they naturally possess the required electromechanical coupling effectiveness piezoelectric material convert applied mechanical energy electrical energy e sensing or energy harvesting is characterized by the piezoelectric coupling coefficient  $k = \frac{e}{\epsilon}$  u k ¼ e ð2p w fig 12 nanograft enhanced polymer adhesive joint for improved through thickness fig 13 hollow piezoelectric fiber with radial poling and longitudinal actuation of thermal conductivity reprinted from 59 with permission from Elsevier the fiber reprinted from 67 with permission from Elsevier 2800 r f Gibson composite structures 92 2010 2793 2810 indicated earlier several recent review article dealt with the general area of structural health monitoring 11 14 focus specifically use embedded piezoelectric sensor actuator network damage detection composite structures due to its importance in the development of multifunctional structures Lin and Chang 71 described the fabrication and initial validation testing Stanford multi actuator receiver transduction smart layer CID 3 concept fig 16 concept involves the use of printed circuit technology to produce a thin flexible dielectric film array networked piezoceramic actuator sensor which is embedded within a conventional composite laminate it was shown that a conventional autoclave process cure cycle used fabricate carbon epoxy composite laminates containing the smart layer CID 3 that the layer does not significantly degrade the mechanical behavior of the composite

and that by measuring the phase delay between the transmitted and received stress waves during the cure process the state of the multifunctional piezoelectric structural fiber can be monitored. Subsequent research showed that such layers can be integrated into composite structures fabricated by filament winding processes and that the concept can be applied to either active or passive sensing to monitor the health of the electrode layer. As with the hollow piezoelectric fiber, the structure throughout its lifetime still recently showed radial poling results. Longitudinal actuation of the fiber et al 73 demonstrated feasibility improved actuator for finite element model piezoelectric structural fiber sensor network damage detection composite laminate. Polymer matrix composites such as the one in fig 15 showed based on the use of PZT actuators and fiber Bragg grating (FBG) for electromechanical coupling coefficient available for optical sensors instead of using PZTs for both actuating and sensing composite high 65 70 corresponding in advantage approach lie decoupling coupling coefficient for the fiber itself and that piezoelectric structural signal transmission mechanism elimination signal. A fiber composite is a suitable candidate for vibration control damping crosstalk actuator sensor signal PZT actuator energy harvesting or structural health monitoring for sensor network approach active sensor network the capability of simultaneous control of stiffness and damping for damage detection in composite structures have been reported. It is a significant advantage of a new class of materials known as smart materials by Su et al 74 75 reports on the use of artificial neural networks for rheological elastomer. More consist conventional analyze data piezoelectric sensor network elastomer filled micron sized magnetizable particle classify and locate the damage in composite structures have been as iron as reported by Fuchset al 70 an applied magnetic field published Watkins et al 76 Haywood et al 77 Yu of variable strength was used to continuously and rapidly control et al 78 similar systems have been adapted for control of smart stiffness and damping of a polybutadiene elastomer filled with 3 laminated structures by Srivastava et al 79 71m diameter carbonyl iron particle case optimum layer layer IBI assembly which involves sequential deposition concentration iron particle greatest improvement situation of dissimilar thin films at the nanoscale has made it possible damping and stiffness was found to be 60 wt and other important to develop sensors that are capable of detecting multiple phenomena variables which govern the stiffness and damping of smart materials are the energy for example Loh et al 80 used the IBI method to fabricate an alignment of the magnetic particles and the temperature carbon nanotube polyelectrolyte multilayer composite material fig 15 finite element model of piezoelectric structural fiber embedded in a polymer matrix reprinted from 68 with permission from Elsevier R F Gibson composite structures 92 2010 2793 2810 2801 fig 16 Stanford multi actuator receiver transduction smart layer concept of integrated sensor actuator network in a composite laminate reprinted from 71 permission from Elsevier for monitoring strain and corrosion in this case the concentration the most common mode of energy harvesting involves the use of carbon nanotube determines sensitivity strain piezoelectric material convert mechanical deformation type of polyelectrolyte determines the sensitivity to pH deposition from vibrating structures such as beams and plates to electrical energy of such a sensor on a miniature planar coil antenna results in a energy it appears that Sodano et al 84 were the first to report that passive wireless sensors require battery power the power output from a randomly vibrating piezoelectric material supply 81 IBI method also used fabricate high is capable of recharging a discharged nickel metal hydride battery strength multifunctional composites for biological implants anti they also reported on the use of the piezoelectric output to charge corrosion coating thermal electrical interface material capacitor concluded capacitor discharge occurred 82 83 shape memory polymer also great potential too quickly for practical energy storage and that batteries provided use in sensors and actuators this is particularly true for electroactive more flexibility in use of the stored energy times shape memory polymer composites containing conductive fill in a multifunctional structure the battery should become part of the load bearing structure pereira et al 85 86 embedded thin film

lithium energy cells with carbon epoxy laminate to form energy storage structural composites. The lithium energy cells did not significantly change strength/stiffness. Carbon epoxy basic idea behind energy harvesting storage related laminate energy cell: charged/discharged normally multifunctional structure parasitically extract energy when the composite was mechanically loaded to as high as 50% strain and deformation of host structure and convert its ultimate tensile strength. Further integration was achieved by electrical energy stored used previously metal 87 who used a copper nano inkjet printed circuit on a polymer film. One popular application is for power small electronic devices: polymer film interconnect thin film solar module such as wireless sensors for structural health monitoring. Several thin film lithium ion battery resulting film embedded review article already published subject 14 co-cured within carbon epoxy prepreg layer fabricate 17 and since the discussion of sensors and actuators in the previous energy harvesting storage laminate the multifunctional laminate construction is also highly relevant to energy harvesting. The emphasis subjected mechanical loading shown in fig 17. In this section will be on recent developments in energy storage: inkjet printed electrode thicker 4  $\mu\text{m}$  in load bearing multifunctional structures exhibit significant resistance change. Maximum in fig 17 resistance of inkjet printed 160  $\mu\text{m}$  wide electrode under static loading for several electrode thicknesses. Resistance and percentage of resistance change reprinted from 87 with permission from Elsevier 2802. R. F. Gibson composite structures 92, 2010, 2793–2810. Mum strain 1. Liu et al. 88 developed new load bearing structural battery in which the polymer cathode in a conventional polymer lithium ion battery (fig 18) replaced higher molecular weight carbon nanofiber reinforced polymer (fig 19). The organic liquid electrolyte was replaced with a solid state polymer electrolyte and the separator region was reinforced with non-conducting fibers. Although this design represents a starting point, the tensile modulus of the battery was only about 3 GPa and the energy density was low compared with that of a conventional lithium ion battery. Work needed to develop usable structural battery. Snyder et al. 89 investigated different polymer electrolyte formulation multifunctional structural battery ranging from highly conductive structurally weak to poorly conductive and highly structural as shown in fig 20. It was found that the electrical conductivity and the elastic modulus of the different formulations are inversely related, which makes it difficult to optimize both properties. In a separate paper Snyder et al. 90 investigated the properties of commercial carbon fabric materials: carbon nanotube papers and nanofoam papers for possible use as fig 20. Experimental data showing an inverse relationship between electrical conductivity and compressive modulus. Several polymer electrolyte use pan based carbon fabrics yielded the best balance between electrostructural batteries reprinted from 89 with permission copyright 2007 American Chemical Society. Chemical tensile strength performance whereas pitch based fabric exhibited poor multifunctional performance. Nanofoam paper best electrochemical performance. Grated capacitor provide energy storage quick discharge. The mechanical properties were poor at high energy levels. Brien et al. 91 compared stiffness and energy density of various structural capacitors although structural integrated batteries are more practical for energy density of various structural capacitors as shown in fig 21. Slower discharge longer period time structurally integrated conventional capacitors have high energy density but poor stiffness. Fig 18 construction of conventional non structural polymer lithium ion battery reprinted from 88 with permission from Elsevier. Fig 19 construction of new structural battery reprinted from 88 with permission from Elsevier. R. F. Gibson composite structures 92, 2010, 2793–2810, 2803. Fig 21 energy density and specific modulus of multifunctional structural capacitors. Dashed line represents design goal for true multifunctionality reprinted from 91 with permission of the Society for the Advancement of Material and Process Engineering. Sample where as structural composites have good stiffness but poor energy density. None of the materials evaluated met the design goal of multifunctional efficiency for system level weight savings shown by the fig 22 illustration self healing crack polymer use. Dashed line in fig 21 in a continuation of this work. Baechle et al. microencapsulated healing agent and a catalyst for polymerizing the healing agent 92 addressed design issue improving multifunctional efficiency reprinted from 96 with kind permission from Springer Science. Business media efficiency and scaling issues related to manufacturing. Luo and Chung 93 developed high



capacitance structural capacitor consisting research optimization microcapsule concn carbon epoxy laminate paper interlayer reduce traction choice catalyst led crack healing efficiency thickness conductivity capacitor over 90 g 0.9 in self healed specimens and maximum healing mechanically tested lin and sodano 94 demonstrated that their efficiency was achieved within 10 h of the fracture event 96 still previously developed sic batio piezoelectric structural fiber 69 more recently caruso et al 97 obtained complete recovery of vir 3 could be used as a structural capacitor by taking advantage of the gin fracture toughness g 1 replacing original solvent dielectric nature of the batio coating on the sic fiber e theba healing agent in the microcapsules with the epoxy solvent microcap 3 tio coating was employed as a cylindrical capacitor fibers with sules containing mixture epoxy monomer solvent 3 a n as per ratio of 0.23 were found to be the best for energy storage shown in fig 23b the resulting load displacement curves indicate full recovery of virgin fracture toughness related research by the 3 4 self healing capability group considered self healing polymer fatigue loading 98 100 low velocity impact loading 101 well a truly autonomous multifunctional structure will be capable of development self healing polymer coating provide healing itself when damaged as a biological system would and re effective corrosion protection steel substrate 102 cent research demonstrated feasibility material use of three dimensional microvascular networks in the substrate particularly polymeric materials a comprehensive review of pub beneath an epoxy coating to enable continuous delivery of healing lications area self healing polymeric material agent self healing repeated crack damage coating cently appeared 13 representative publication 103 discussed white et al 95 developed self healing other recent developments in self healing polymer composites polymers and polymer composites based on the use of a microen include the use of different methods of healing agent microencap capsulated healing agent and a catalyst for polymerizing the heal sulations such as nanoporoussilicacapsules 104 and nanoporous ing agent as shown in fig 22 when damage causes cracks in the glass fiber 105 use self healing polymer matrix polymer crack break open microcapsules causing material in carbon fiber reinforced composites has also been con healing agent to leak into the crack by capillary action the healing sidered williams et al 106 yin et al 107 found agent reacts catalyst causing polymerization self healing ability woven glass fabric epoxy composite con bond crack face together mode fracture toughness test taining healant microcapsules degraded storage time of virgin epoxy and self healed epoxy specimens using the tapered likely cause believed time dependent diffusion double cantilever beam tdc b test fig 23a showed that frac epoxy monomer from the microcapsules following contraction of ture load and corresponding fracture toughness for the self healed microcapsules cure process degradation specimens reached up to 75 of the corresponding values for the found to self limiting process leaked epoxy gradually virgin uncracked specimen crack healing efficiency cured and blocked the diffusion sites on the microcapsules but it fracture toughness test is defined as concluded research needed improve microcapsule designs and materials k p g  $\frac{1}{4}$  i healed  $\frac{1}{4}$  chealed  $\delta 4p$  most of the research on self healing materials has been based k p i virgin c virgin on experimental work and only a few publications have dealt with 2804 r f gibson composite structures 92 2010 2793 2810 fig 23 load displacement curves for mode i fracture toughness tests of virgin and self healed specimens microcapsules contain solvent healing agent only reprinted 95 by permission from macmillan publishers ltd b microcapsules contain a mixture of epoxy monomer and solvent copyright wiley vch verlag gmbh co kgaa reproduced from 97 with permission analytical modeling self healing process balazs 108 when used as matrix materials in multifunctional fiber composite briefly reviewed computational models for self healing materials structures is not clear however blends of icpss such as pani with while pointing out that the area is still in its infancy and that solu established structural polymer like epoxy resin may tions require development multidisciplinary method practical approach jia et al 116 studied electrical conductivity involving models for fluid dynamics structural mechanics chemi pani epoxy composite different pani morphology cal reactivity and phase transitions barbero et al 109 have ap as shown in fig 24 the composites containing pani wires had a plied principle continuum damage mechanic case lower percolation threshold than the composites containing pani self healing composite maiti et al 110 geubelle particle pani fiber pani wire maiti 111 employed artificial crack closure approach highest aspect ratio able easily form continuous involving cohesive modeling contact algorithm park et al conductive network within non conducting epoxy indi 112

used a conventional cure kinetics model and electrical resistivity in section 3.1  
 the use of other high aspect ratio electrically conductive heating polymer matrix glass transition conducting  
 nanofillers polymer also effective mean temperature achieve self healing carbon fiber monomer  
 creating electrically conducting polymer composites which in turn composite suitable EMI shielding  
 example Huang et al 117 Al Saleh Sundararaj 118 investigated  
 EMI shielding characteristics of carbon nanotube polymer composite 3.5 electromagnetic interference EMI  
 shielding materials while the EMI shielding properties of carbon nanofiber polymer  
 composites have been studied by Yan et al 119 a review electromagnetic interference EMI  
 occurs when an undesirable or recent articles on conductivity and EMI shielding characteristics disturbance  
 due electromagnetic conduction radiation vapor grown carbon nanofiber polymer composite  
 an external source interferes with the operation of an electrical circuit published by Al Saleh and Sundararaj 120  
 the usual solution to EMI is to protect the circuit with an EMI shielding material or structure  
 and the shielding effectiveness  $SE$  is defined in decibels (dB)  $SE = 10 \log \frac{E_{\text{inc}}}{E_{\text{tr}}}$  where  $E_{\text{inc}}$  is the incident electric field  
 electrically conducting metallic materials have excellent  $SE$   
 due to reduced weight and other desirable properties non metallic material polymer polymer composite  
 increasingly used to replace metals is particularly important for multifunctional materials and structures which are typically based on polymer composite electrical mechanical  
 function typically involved order achieve acceptable  $SE$   
 the polymer must be either an intrinsically conducting polymer (ICP)  
 or be filled with a conducting material such as carbon fibers nanotube coated conductive coating several  
 recent review articles have discussed various aspects of EMI shielding especially polymer Chung 113 reviewed  
 publication on materials for EMI Geetha et al 114 surveyed recent research on methods and materials for EMI  
 while Wang and Jing 115 viewed articles dealing with ICPs for EMI Fig 24 electrical conductivity PANI epoxy  
 composite different PANI while ICPs such as polyaniline PANI and polypyrrole (PPy)  
 contents and different PANI morphologies PANI particles PANI fibers effective EMI shielding mechanical  
 effectiveness PANI wires reprinted from 116 with permission from Elsevier R F Gibson  
 composite structures 92 2010 2793 2810 2805 3.6 recyclability and biodegradability  
 requirements in the design of multifunctional composites and this  
 makes optimization of such systems an even greater challenge  
 associated concerns about environmental impact sustainability  
 and renewable energy sources have increased in recent years recy 4  
 recent applications of multifunctional materials and recyclability biodegradability taken correspondingly  
 structure important roles as non structural functions of advanced materials particularly true polymer polymer  
 composite much research multifunctional material structural nanocomposites  
 these are very active research areas and a number  
 of reviews has been driven by current and potential aerospace applications  
 below are relevant review articles that have already been published about EMI shielding example motivated primarily potential  
 aircraft subject objective limited providing  
 applications and by technological advances in composite materials  
 brief overview of representative review articles sensing actuation control ability multifunctional  
 Henshaw et al 121 Pickering 122 Ramakrishna et al 123 structure to reconfigure  
 or morph itself as it operates in an environment Vaidya Chawla 124 Derosa et al 125 reviewed morphing  
 and its mission profile changes has been a subject of great publication dealing various recycling issue polymer  
 research interest in recent years one major goal of such research is composite material due faster simpler  
 processing cycle to develop multifunctional aircraft wings which can change shape for thermoplastic polymers  
 recycling of thermoplastic composites in different phases of flight as a bird wing does a major application  
 process injection compression molding new of these technologies is for morphing aircraft skins and a composite  
 composites is easier than for thermoset matrix composite extensive review publications on morphing skin  
 published likely recycling scenarios thermoset matrix composite published recently Thill et al 143 since publication  
 either mechanically recycle them by grinding them into small particles review article several relevant applications  
 oriented publications titles using filler new composite they appeared example Wildschek et al 144  
 reported mechanically recycle using intense heat break the development of a new composite  
 electric morphing trailing composite reusable component possible loss mechanical

edge for flight control on a blended wing body airliner. A method for recycling significant waste described by Hart et al. [145, 146] described the use of a shape memory alloy for active jet improving property mechanically recycled thermoplastic engine chevron applications and mudupuetal [147] discussed the described tall et al [126] recycling composite design and validation of a fuzzy logic controller and a piezoelectric containing nanoparticles, nanofibers or nanotubes and other nano composite actuator for a smart projectile in waste requires special consideration due to potential toxicity. Car structurally integrated batteries for energy storage are another concern. Cinogenicity and other health related concerns as discussed in the recent application multifunctional structure design effect review article by Strzejewski, Piotrowska et al. [127] tiveness multifunctional system best defined using if a composite is to be biodegradable natural fibers and polymer metric characterizes particular system flight matrix materials made from renewable resources are obviously of endurance time aircraft vehicle example reported great interest research on natural fibers such as jute, ramie, flax by Thomas and Qidwai [148, 149] structurally integrated batteries sisal composite reviewed Nabi Saheb. Extend flight endurance time electrically propelled jog [128] Bogoeva, Gaceva et al [129] Mishra et al [130] unmanned air vehicle UAV flight endurance time Yan et al [131] Eichhorn et al [132] and Cheunget al [133] typ UAV given by [148, 149] ically the strength and modulus values for natural fibers are well conventional structural fiber glass. E.g. QSC3 1 2 ¼ b b l g 0.6p due low density specific modulus natural fiber. E 0.7w pw pw pw 0.3 2 2c2 p b pr pl areas good or better than that of glass. Publications dealing with the development of polymers from renewable resources have been these equations show that integrating the battery with the structure surveyed Yu et al [134] Raquez et al [135] test ture or one of the other subsystems can lead to an increased flight methods for characterizing biodegradability of polymeric materials. Endurance time e further analysis of this equation for change in reviewed Gu Gu [136] natural protein based e change battery structure weight show material received considerable attention biomedical decreasing the weight is 1 5 times more effective in increasing the application indicated Kumar et al [137] biodegradable than is increasing the battery energy [148] by integrating a poly bio based green nanocomposites consisting of matrix material merlithium ion battery in the carbon epoxy composite wingskin. Cellulosic plastic corn derived plastic plastic made structure DARPA Wasp micro air vehicle MAV record from bacterial sources reinforced by nanoclay particles have been setting flight endurance time vehicle achieved [149] subject extensive recent research reviewed Pandey. A photo of this vehicle is shown in fig 25 et al [138] and Ray and Bousmina [139] one drawback to green another example of multifunctional structure technology that is composites is that their mechanical properties are typically more driven by aerospace applications is the integration of an electronic sensitive hygrothermal condition conventional communication antenna load bearing composite structure composite for example absorbed moisture has been found to significantly degrade mechanical property. Hemp fiber composites development efforts sponsored by the US Air Force smart composites [140] flax fiber composite strongly affected skin structure technology demonstration s3td program intends elevated temperature [141] however special chemical treatment to develop the technology to embed a broadband antenna into ments for natural fibers can reduce their sensitivity to hydrother the composite skin of a fighter aircraft [150, 153] more recent mal conditions [142] search related to the clash has involved the design and fabrication publication listed far involve experimental of a microstrip antenna which is integrated in a three dimensional work and there is a need for development of more analytical models orthogonal woven composite structure [154] impact testing. Else to complement the experiments analytical models are needed these structures [155] and wireless detection of damage in com help interpreting experimental result positive structure making use composite structure optimizing multifunctional material system specific as an antenna sensor system [156] application obviously there are other issues such as hydrother composites and sandwich structures presents some interesting possibilities. Response sound absorption may become functional abilities multifunctional application example Wirtz et al [2806] R F Gibson composite structures [92, 2010, 2793, 2810] fig 26 recent English language refereed journal articles related to multifunctional nanoparticles data collected engineering village CID 2 web based information service

have reviewed the literature in the area of polymer nanocomposite foam fig 25  
 first generation darp was a pmicro air vehicle with polymer lithium ion among challenging promising  
 application battery silver quadrilateral integrated composite wing skin structure reprinted from 149  
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 multifunctional materials and structures are those in the biomedical field much recent activity area 157  
 described thermal mechanical behavior driven advance nanomaterials nanostructures multifunctional  
 thermal energy storage sandwich structure example multifunctional nanoparticles great potential use  
 temperature control system electronics module drug  
 antibody delivery in combination with diagnostics and therapy multifunctional structure thermal interface  
 connected peutics since 2000 there has been a surge in the number of journal  
 to a hollow aluminum plate which has a series of small compartments related to multifunctional nanoparticles  
 as shown clearly mentsthat filled with phase change material heat storage in fig 26 suhetal 164  
 have reviewed the developments in multiviathe latent heat of the phase change material the thermal en-  
 tropy storage and mechanical behavior of the structure are characterizations fig 27 illustrates one possible  
 configuration terized determined structure excellent mfnps  
 the matrix of the mfnps could be a metal oxide network performance weight ratio queheillalt et al 158  
 developed host sub domain inclusion fluorescent optical multifunctional heat pipe sandwich structure  
 integrates probe magnetically susceptible particles for magnetic resonance  
 the thermal management capabilities of a heat pipe with structural imaging  
 and pores or functionalities which can host small bioac loads support ozaki et al 159  
 reported on multifunctional and five molecule such as drugs or antibodies inclusions can be either with  
 panel space satellite electronic module organic inorganic or hybrid organic inorganic 164 abionanoen-  
 embedded between the facesheet of carbon fiber composite hon gineering design process multilayered  
 mfnps described eycomb cores and sandwich panel the mechanical electrical and thermal haglund et al 165  
 and such a multilayered particle is illustrated mal characteristic panel evaluated significant in fig 28  
 mfnps offer great hope for early detection of cancer and reduction weight cost production time achieved  
 delivery of therapeutic drugs for cancer treatment publications re use carbon foam core carbon fiber  
 composite face led to the development of mfnps for cancer imaging and therapy sheet enhance thickness  
 plane they have been reviewed by park et al 166 mfnps which have a com mal conductivity sandwich panel  
 lightweight spacecraft bination of magnetic and fluorescent properties are of great interest thermal radiator  
 described silverman 160 est vitro imaging technique mri well automotive industry great interest  
 multifunctional therapy external magnetic manipulation building bio structure static dynamic acoustic  
 behavior medical nanodevices corretal 167 have reviewed recent publi optimized  
 rather than taking the traditional approach of treating cation multifunctional magnetic fluorescent  
 nanocomposites design manufacture assembly automobile body biomedical application surface area  
 volume ratio structure acoustic treatment interior trim separately cam v spherical particle inversely  
 proportional radius eron et al 161 have used finite element model to study a multi v nanometer sized particle  
 1000 time greater functional approach integrated multi layered than a v for a micron sized particle  
 the large area ratios and result sandwich is used to replace a traditional roof panel with its sepa ing large pore  
 volume porous hollow nanostructures make rate components vaidya et al 162 developed a multifunctional  
 particularly attractive multifunctional delivery drug sandwich structure in which the woven e  
 glass facesheets are con and biomolecules recent publications on the synthesis and appli nected vertical  
 woven e glass pile foam core cation of hollow micro nanostructures have been reviewed by lou  
 construction enhances the impact resistance sound vibration et al 168 biomedical application hollow  
 nanostruc damping and accommodates wires or sensors sandwich structures  
 tures have been reviewed by anandhyeon 169 often consist of composite facesheets and foam cores  
 and there is a number of biomedical applications for multifunctional mate  
 increased activity in the use of nanoparticles to enhance both the  
 rials requires substantial flexibility in order to accommodate large manufacturing process mechanical property  
 foam deformation example artificial muscle must flexible manufacturing process foam enhanced strong  
 enough capable sensing actuation nanoparticles serve nucleation site bubble  
 large ranges of deformation biomedical applications include peri foaming process leading increased

density reduced cell static pumps robot arms artificial hands and grippers one such size mechanical property foam also enhanced due to class material subject considerable reinforcement effect nanoparticles lee et al 163 search ionic polymer metal composite ipmc which r f gibson composite structures 92 2010 2793 2810 2807 fig 27 illustration of multifunctional nanoparticle system mfnps for biomedical applications reprinted from 164 with permission from Elsevier fig 28 illustration of multilayered mfnps reprinted from 165 with kind permission from Springer Science Business Media are excited by an electric field shahinpoor and kim have published determine impact energy optical transparency mea series four review article dealing fundamental sure using a spectrophotometer significant improvement in 170 manufacturing technique 171 modeling simulation impact energy achieved nano enhanced adhesive 172 industrial and biomedical applications 173 of ipmcs layer while transparency was somewhat reduced but acceptable electroactive polymers with high dielectric constants can also generate related investigation impact resistant optically transparent erate large deformation electric field reviewed composites have been reported by Liu et al 179 rojanapitayak bar cohen 174 as another example energy harvesting from noroneta 180 songetal 181 and huangetal 182 mal motion deformation human body requires the energy conversion device be very flexible qietal 175 5 concluding remarks developed flexible energy conversion device based printing piezoelectric pzt ribbon micrometer scale width article attempt reasonably comprehensive review nanometer scale thicknesses on rubber substrates the use of car representative journal publication covering development of nanotube flexible electronic yarn fabric use mechanics of multifunctional composite materials and structures wearable biomedicine telemedicine sensor most of the articles have appeared since 2000 and many involve ported shim et al 176 energy harvesting backpack polymer composites nanomaterials and nanostructures function use by soldiers was developed by granstrom et al 177 whose interest include structural property like strength stiffness placed the nylon shoulder strap on a standard backpack with flex fracture toughness and damping and non structural functions like piezoelectric straps during normal walking motions electrical and or thermal conductivity sensing and actuation in relative motions between the soldier's body and the backpack energy harvesting storage self healing capability electromagnetic erate deformation pzt strap convert interference emi shielding recyclability biodegradability deformation to electrical energy for use in powering small portable much future research multifunctional material ble electronic devices carried by the soldier structure driven structural application like multifunctionality impact resistant material military aircraft but by needs in other areas like biomedical there is a need transport vehicle helicopter fighter aircraft becoming for more analytical modeling work in most of the areas covered in increasingly important and one example is optically transparent this review since most of the published results tend to be impact resistant nanocomposite material window experimental in nature analytical models are needed not only to vehicle extremely small size small concentration help interpreting experimental result optimizing nanoreinforcements make possible improve impact energy the multifunctional material or system for specific applications absorption maintaining good transparency material investigated rai singh 178 fabricated and tested sandwich panels consisting of pmma sheets with thin acknowledgement layer nano enhanced polymer adhesive sandwiched the polymer adhesive layers were enhanced with 2 wt the author gratefully acknowledges the financial support from 35 nm sized alumina powder drop weight impact tests were used award fa9550 09 1 0506 u air force office of 2808 r f gibson composite structures 92 2010 2793 2810 scientific research and the encouragement of dr leslee program rein plastics compos 2009 doi 10 1177 0731684409344652 online first manager a forsr mechanic multifunctional material september 8 2009 29 vlasveldt dn berseehen pickens j nanocomposite matrix for increased and microsystems program the author is very grateful for the elec fibre composite strength polymer 2005 46 10269 78 tronic access engineering village cid 2 web based information 30 zhao z g ci l j cheng h bai j b growth multiwalled carbon service through the mathewson igtknowledge center at the uni nanotubes with different morphologies on carbon fibers carbon 2005 43 663 5 versity of nevada reno without which this article would not have 31 uddin m f sunct strength of unidirectional glass epoxy composite with silica been possible nanoparticle enhanced matrix compos sci technol 2008 68 7 8 1637 43 32 uddin m f sunct

improved dispersion and mechanical properties of hybrid nanocomposites *compos sci technol* 2010 70 223  
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 nanoparticles *polym polym compos* 1 baur j silverman e challenge opportunity multifunctional 2008 16  
 8 471 7 nanocomposite structures for aerospace applications *mrs bull* 2007 32 4 34 zhang h tang l c zhang  
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 an assessment of the polymeric composites with micro and nanoparticles *compos sci technol*  
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 song sm endo et al enhanced application advmater2002 14 13 14 997 1000 thermal conductivity  
 carbon fiber phenolic resin composite 26 koratkarna weibq ajayanpm  
 multifunctionalstructuralreinforcement introductionofcarbonnanotubes applphyslett2007 90 093125  
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retardation and repair of fatigue cracks in a piezoelectric composites sensor/actuators a 1996 51 183 92  
microcapsule toughened epoxy composite part ii: in situ self healing 67 breid cannon bj  
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64 245 61 100 brown n whites r sottos n r fatigue crack propagation in microcapsule 68 liny sodano h a  
concept and model of a piezoelectric structural fiber for toughened epoxy j mater sci 2006 41 19 6266 73  
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introductionofcarbonnanotubes: 0.004202533967367589  
inversely: 0.004202533967367589  
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investigateddifferentpolymer: 0.004202533967367589  
investigatedthepropertiesofcommercialcarbonfabricmaterials: 0.004202533967367589  
involve: 0.004202533967367589  
involves: 0.004202533967367589  
involving: 0.004202533967367589  
involvingmodelsforfluidynamics: 0.004202533967367589  
ionbattery: 0.004202533967367589  
ionbatteryinthecarbon: 0.004202533967367589  
ipmc: 0.004202533967367589  
is asignificant advantage of a new class of materials known as mag: 0.004202533967367589  
is capable of recharging a discharged nickel metal hydride battery: 0.004202533967367589  
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it is possible to simultaneously increase strength and modu: 0.004202533967367589  
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its ultimate tensile strength: 0.004202533967367589  
it turns out that very small concentrations of carbon nanotubes: 0.004202533967367589  
it was found: 0.004202533967367589  
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jiaqm: 0.004202533967367589  
jinfratructsyst2008: 0.004202533967367589  
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jintellmatersyststruct1995: 0.004202533967367589  
jintellmatersyststruct2001: 0.004202533967367589  
jintellmatersyststruct2005: 0.004202533967367589  
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jn: 0.004202533967367589  
jnanosci: 0.004202533967367589  
johnson: 0.004202533967367589  
joining: 0.004202533967367589  
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keyengmater2010: 0.004202533967367589  
keywords: 0.004202533967367589  
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klompenetj: 0.004202533967367589  
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laimo: 0.004202533967367589  
lajolla: 0.004202533967367589  
laminated: 0.004202533967367589  
laminatedstructuresbysrivastavaetal: 0.004202533967367589  
laminatesbasedonthecrackclosuretechniqueforfiberbridging: 0.004202533967367589  
language: 0.004202533967367589  
largerangesofdeformation: 0.004202533967367589  
latedtothedevelopmentofmfnpforcancerimagingandtherapy: 0.004202533967367589  
laterused: 0.004202533967367589  
lau: 0.004202533967367589  
lauetal: 0.004202533967367589  
lauk: 0.004202533967367589  
lawrencerw: 0.004202533967367589

layerassembledcompositesfrommultiwallcarbonnanotubeswithdifferent: 0.004202533967367589  
layerconceptofintegratedsensor: 0.004202533967367589  
layeredcomposite: 0.004202533967367589  
layerswithinamul: 0.004202533967367589  
leading: 0.004202533967367589  
leaked: 0.004202533967367589  
leary: 0.004202533967367589  
least: 0.004202533967367589  
led: 0.004202533967367589  
leecm: 0.004202533967367589  
leejl: 0.004202533967367589  
lesieutrega: 0.004202533967367589  
leslee: 0.004202533967367589  
lessthanthatofcompositeswithstraightnanotubes: 0.004202533967367589  
lewisja: 0.004202533967367589  
lh: 0.004202533967367589  
liangr: 0.004202533967367589  
lic: 0.004202533967367589  
lications: 0.004202533967367589  
lietal: 0.004202533967367589  
lif: 0.004202533967367589  
lifetime: 0.004202533967367589  
liftcoefficient: 0.004202533967367589  
lightning: 0.004202533967367589  
lightweight: 0.004202533967367589  
lijb: 0.004202533967367589  
lil: 0.004202533967367589  
limitationsofmodei: 0.004202533967367589  
limited: 0.004202533967367589  
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lin: 0.004202533967367589  
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loadsupport: 0.004202533967367589  
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lockyer: 0.004202533967367589  
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logic: 0.004202533967367589  
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lohkj: 0.004202533967367589  
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long: 0.004202533967367589  
longcarbonnanotubesgrownonthesurfaceof: 0.004202533967367589  
longer: 0.004202533967367589



longitudinalcompressivestrengthandmoduluswerebothsignifi: 0.004202533967367589  
longitudinaldeformationresultsinradialelectricaloutput: 0.004202533967367589  
longitudinaltensilestrengthandelasticmodulus: 0.004202533967367589  
loss: 0.004202533967367589  
lossmoduliforpurepcandseveralswnt: 0.004202533967367589  
lou: 0.004202533967367589  
lowelectrical: 0.004202533967367589  
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lowerpercolationthresholdsas: 0.004202533967367589  
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magneticallysusceptibleparticlesformagneticresonance: 0.004202533967367589  
magnetizable: 0.004202533967367589  
magnetorheological: 0.004202533967367589  
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maintaining: 0.004202533967367589  
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makesoptimizationofsuchsystemsanevengreaterchallenge: 0.004202533967367589  
making: 0.004202533967367589  
malconditions: 0.004202533967367589  
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malinsulation: 0.004202533967367589  
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manipulation: 0.004202533967367589  
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manual: 0.004202533967367589  
manuf2001: 0.004202533967367589  
manuf2010: 0.004202533967367589  
manufacture: 0.004202533967367589  
manufacturingandreliabilityoftheactivecomposites: 0.004202533967367589  
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materbioenergy2008: 0.004202533967367589  
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materconference: 0.004202533967367589  
materialincarbonfiber: 0.004202533967367589  
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mationservice: 0.004202533967367589  
matrixinterfacialshearstrength: 0.004202533967367589  
matrixmaterialsmadefromrenewableresourcesareobviouslyof: 0.004202533967367589  
matsuzakir: 0.004202533967367589  
mav: 0.004202533967367589  
maxi: 0.004202533967367589  
mayes: 0.004202533967367589  
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mccarvilleda: 0.004202533967367589  
mckinstry: 0.004202533967367589  
mea: 0.004202533967367589  
mean: 0.004202533967367589  
measscitech2009: 0.004202533967367589  
measuredgreaterthan1000: 0.004202533967367589  
mech: 0.004202533967367589  
mechanicalandelectricalpropertiesofa: 0.004202533967367589  
mechanicalandphysicalpropertiesofflaxfibers: 0.004202533967367589  
mechanicaldesignandperformanceofcomposite: 0.004202533967367589  
mechanicallytested: 0.004202533967367589  
mechanicsofmultifunctionalcompositematerialsandstructures: 0.004202533967367589  
mechanismsofcnt: 0.004202533967367589  
medicalapplications: 0.004202533967367589  
medicalnanodevices: 0.004202533967367589  
melnykowyczm: 0.004202533967367589  
memoryalloyforactivejetenginechevronapplication: 0.004202533967367589  
memphis: 0.004202533967367589  
men: 0.004202533967367589  
mendermer: 0.004202533967367589  
mendermercomposite: 0.004202533967367589  
meng: 0.004202533967367589  
mentand: 0.004202533967367589  
mentsfornaturalfiberscanreducetheirsensitivitytohygrother: 0.004202533967367589  
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mentsthat: 0.004202533967367589  
mercompositeshavebeenstudiedbyyangetal: 0.004202533967367589  
merelectrolyteandtheseparatorregionwasreinforcedwithnon: 0.004202533967367589  
merlithium: 0.004202533967367589  
metallic: 0.004202533967367589  
methodsandmaterials: 0.004202533967367589  
methodsforcharacterizingbiodegradabilityofpolymericmaterials: 0.004202533967367589  
metric: 0.004202533967367589  
meures: 0.004202533967367589  
mfnpsoffergreathopeforearlydetectionofcancerand: 0.004202533967367589  
mfnpsofwhichhaveacom: 0.004202533967367589  
microbiological: 0.004202533967367589  
microcapsuledesignsandmaterials: 0.004202533967367589  
microcapsulescontainamixtureofepoxymonomerandsolventcopyrightwiley: 0.004202533967367589

microcapsulescontainsolventhealingagentonly: 0.004202533967367589  
microencapsulatedhealingagentandacatalystforpolymerizingthehealingagent: 0.004202533967367589  
micrometer: 0.004202533967367589  
micronand: 0.004202533967367589  
microparticles: 0.004202533967367589  
microstripandcoaxialfeeding: 0.004202533967367589  
military: 0.004202533967367589  
minimization: 0.004202533967367589  
minorreductionsinothierproperties: 0.004202533967367589  
misra: 0.004202533967367589  
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mittedandreceivedstresswaveduringthecureprocess: 0.004202533967367589  
mixture: 0.004202533967367589  
mj: 0.004202533967367589  
modeifracturetoughnessforhealedspecimen: 0.004202533967367589  
modeifracturetoughnessforvirginspecimen: 0.004202533967367589  
modelingand: 0.004202533967367589  
modelingandanalysisoffunctionallygradedmaterials: 0.004202533967367589  
modelingoffatiguecrackretardationinself: 0.004202533967367589  
modelingself: 0.004202533967367589  
modificationstocompos: 0.004202533967367589  
modifiedcarbonfibersinanepoxymatrixtodeterminethefiber: 0.004202533967367589  
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mohwaldh: 0.004202533967367589  
moleculardynamicssimulationtoshowthatifthepolymer: 0.004202533967367589  
monitored: 0.004202533967367589  
monitorforacompositepaneemployingsmartsensortechonlogy: 0.004202533967367589  
monomer: 0.004202533967367589  
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montalvaoetal: 0.004202533967367589  
monte: 0.004202533967367589  
mooneyjt: 0.004202533967367589  
moore: 0.004202533967367589  
moosbruggerjc: 0.004202533967367589  
moreflexibilityinuseofthetoredeenergy: 0.004202533967367589  
morepracticalfor: 0.004202533967367589  
morerecently: 0.004202533967367589  
morerecentlydevelopedhollowpiezoelectricfi: 0.004202533967367589  
morerecentre: 0.004202533967367589  
morerecentresearch: 0.004202533967367589  
morphingskins: 0.004202533967367589  
morrisondj: 0.004202533967367589  
mostofthearticleshaveappearedsince2000: 0.004202533967367589  
mostoftherel: 0.004202533967367589  
mostoftheresearchon: 0.004202533967367589  
motivated: 0.004202533967367589  
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mrsbull2009: 0.004202533967367589  
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multifunctionalnanosystems at the interface of: 0.004202533967367589

multifunctionalsandwichcomposite: 0.004202533967367589

multifunctionalstructuralreinforcement: 0.004202533967367589

multifunctionalthermalenergystoragestructure: 0.004202533967367589

multilayered: 0.004202533967367589

multiplestructural: 0.004202533967367589

multiwalled: 0.004202533967367589

mum: 0.004202533967367589

muralt: 0.004202533967367589

mwaikamboly: 0.004202533967367589

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nanocom: 0.004202533967367589

nanocompositematrixforincreased: 0.004202533967367589

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nanofibersornanotubesandothernano: 0.004202533967367589

nanofillers: 0.004202533967367589

nanof foam: 0.004202533967367589

nanolett2004: 0.004202533967367589

nanolett2008: 0.004202533967367589

nanomaterialsandnanostructures: 0.004202533967367589

nanomedicaldevices: 0.004202533967367589

nanometer: 0.004202533967367589

nanometerscalethicknessesonrubbersubstrates: 0.004202533967367589

nanoparticlereinforcementofth matrix in a unidirectional fiber composite: 0.004202533967367589

nanoporous: 0.004202533967367589

nanoreinforcementslikecarbonnanotubesonthesurfaceofthefi: 0.004202533967367589

nanoscalereslett2008: 0.004202533967367589

nanosci: 0.004202533967367589

nanosci2007: 0.004202533967367589

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nanotubecompositesforthermalmanagement: 0.004202533967367589

nanotubesandtheircomposites: 0.004202533967367589

nanotubeswithdifferentmorphologiesoncarbonfibers: 0.004202533967367589

nat: 0.004202533967367589

natetheneedforadd: 0.004202533967367589

nation: 0.004202533967367589

natmater2007: 0.004202533967367589

naturalfibereco: 0.004202533967367589

naturalfibersandpolymer: 0.004202533967367589  
nature2001: 0.004202533967367589  
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nected: 0.004202533967367589  
need: 0.004202533967367589  
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nessthermalconductivity: 0.004202533967367589  
netorheological: 0.004202533967367589  
networked: 0.004202533967367589  
networkofpiezoceramics: 0.004202533967367589  
networktoformalongthetangledcntsintheinsulatingpolymer: 0.004202533967367589  
neural: 0.004202533967367589  
newnham: 0.004202533967367589  
nieh: 0.004202533967367589  
niehs: 0.004202533967367589  
nmm: 0.004202533967367589  
nomenclature: 0.004202533967367589  
nominalstoredbatteryenergy: 0.004202533967367589  
noneofthematerialsevaluatedmetthedesigngoalofmul: 0.004202533967367589  
normally: 0.004202533967367589  
nr: 0.004202533967367589  
nucleation: 0.004202533967367589  
numnitride: 0.004202533967367589  
nv89557: 0.004202533967367589  
nw: 0.004202533967367589  
objective: 0.004202533967367589  
observed: 0.004202533967367589  
obtained: 0.004202533967367589  
obtainedcompleterecoveryofvir: 0.004202533967367589  
obviously: 0.004202533967367589  
occurred: 0.004202533967367589  
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