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 alongwiththeincreaseinthenumberofpublica tionsinthisareacomesaneedforacomprehensivereviewarticle 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 batterysubsystemweight 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 modeifracturetoughnessforhealedspecimen q airdensity ichealed k modeifracturetoughnessforvirginspecimen 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 althoughthemultidisciplinarynatureofthetopicwillleadtothe malinsulation andenergyharvesting storage whereasanexam inclusion publication relevant discipline ple type c would structure combining function material science thermodynamics electronics addition type type b recent development thevastmajorityofthesurveyedarticlesdealwithpolymercom multifunctionalmaterialsandstructurestendtobeoftype b posites definition multifunctional material must multifunctional material necessarily composite material composite due large number article involved strong growthin use compositeshas greatly lack electronic access many conference proceeding influencedbymultifunctionaldesignrequirements thetraditional emphasisofthisreviewisonthemoreaccessiblerefereedjournal approachtothedevelopmentofstructuresistoaddresstheload article itwasnotpracticaltocoverallofthesearticles andsince carrying function functional requirement separately somearticleshadalreadybeencoveredbypreviousrelatedreview resulting suboptimal load bearing structure add article attempt made select representative article attachment perform non structural function eachoftherelevantcategories accordingtofig 1 mostoftherel thepenaltyofaddedweight recently however therehasbeenin evantarticleshavebeenpublishedsince2000 sothatisthefocus creasedinterestinthedevelopmentofload bearingmaterialsand ofthisreview structureswhichhaveintegralnon load bearingfunctions guided increased interest multifunctional material struc recent discovery multifunctional biological sys turesisdrivenbytheneedforthedevelopmentofnewmaterials temswork andstructuresthatsimultaneouslyperform multiplestructural duetotheinterdisciplinarynatureofmultifunctionalmaterials function b combinednon structuralandstructuralfunctions andstructures andtheneedtoavoidduplicationinthecurrentre c one example multifunctional structure type view itisappropriatetociteseveralrelevantpreviousreviewarti wouldbeacompositestructurethathashighstrength highstiff cles forexample baurandsilverman 1 reviewedthechallenges ness high fracture toughness high damping example opportunity multifunctional nanocomposite aerospace structure whileyeetal 2 revieweddevelopmentsintheappli cation artificial intelligence functionalize composite air frame definition multifunctional material must composite becoming increasingly apparent nano structuredcompositescanproduceand orenhancemultifunction alityinwaysthatconventionalcompositescouldnot forexample thostensonetal 3 andchouetal 4 reviewedrecentadvances related science technology carbon nanotube theircomposites breuerandsundararaj 5 reviewedrecentstud iesonpolymer carbonnanotubecomposites lietal 6 surveyed recent advance related use carbon nanotube theircompositesassensorsandactuators whilegibsonetal 7 reviewed recent publication dealing vibration carbon nanotubesandtheircomposites andsunetal 8 reviewedarti clesdealingwithvarioustypesofenergyabsorptioninnanocom posites addition small amount carbon nanotube non conducting polymer polymer composite fig 1 recentenglishlanguagerefereedjournalpublicationsrelatedtomultifunc canbetransformedtoconductingmaterials thusenhancingtheir tional material structure data collected engineering village cid 2 web basedinformationservice multifunctionality accordingly bauhoferandkovacs 9 havere r f gibson compositestructures92 2010 2793 2810 2795 viewedrelevantresearchonelectricalpercolationincarbonnano tube polymer composite modeling analysis functionally gradedmaterials fgm havebeenreviewedbybirmanand byrd 10 thefieldofstructuralhealthmonitoring shm ishighlyrel evant several review article appeared recently montalvaoetal 11 reviewedvibration basedshmofcomposite material similar review emphasis composite delamination identification published earlier zou etal 12 recentdevelopmentsinself healingpolymericmateri alswerereviewedbywuetal 13 articlesonenergyharvesting forsensornetworksinshmwerereviewedbyparketal 14 pie zoelectric material often utilized energy harvesting publication topic reviewed sodano et al 15 antonandsodano 16 andcook chennaultetal 17 clo sely related shm study shape memory polymer smp andreviewsofrecentadvancesinsmphavebeenpublished byratnaandkarger kocsis 18 gibsonetal 19 editedthepro ceedings 2008 sampe fall technical conference entitled multifunctionalmaterials workingsmartertogether lauetal 20 archived selected paper 2008 international fig 2 lossmoduliforpurepcandseveralswnt pcnanocompositesatdifferent conference multifunctional material structure mfms strain level reprinted permission 22 copyright 2005 american instituteofphysics 08 whichwasheldinhongkong thermal expansion cte 27 desirable change 2 multiplestructuralfunctions volume fraction silica increased much strengthwillstarttodropduetoparticleagglomeration poorpar 2 1 compositestructuralmaterials ticledispersionandreducedsilica epoxyinterfacialstrength even composite always possible simultaneously im among important structural function system proveseveralproperties insomecases modificationstocompos canprovidearestiffness strength fracturetoughness ductility fa itesleadtomajorimprovementsinsomepropertieswhilecausing tiguestrength energyabsorption damping andthermalstability minorreductionsinotherproperties forexample theincorpora although structural weight function extremely tion rubber microparticles epoxy matrix glass fiber importantdesignconsiderationwhichhasdrivenmoredesignsto reinforced epoxy composite improved tensile fatigue life wardslightweightcompositematerialsinrecentyears withcon thecompositebyafactorofthreewhilecausingonlya5 2 reduc ventional structural material difficult achieve tion tensile strength 12 7 reduction elastic simultaneous improvement multiple structural function modulus 28 theincreasinguseofcompositematerialshasbeendriveninpart bythepotentialforsuchimprovements forexample ithasbeen 2 2 hybridmultiscalestructuralcompositematerials shown simultaneous improvement vibration damping andfracturetoughnessincompositelaminatesaremadepossible 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 islessthanacriticalvalue furtherincreasesininterleafthickness scale reinforcement well conventional micron scale fiber causethefracturetoughnesstodropoffwhilethedampingkeeps particle reinforcement example fiber dominated increasing property e longitudinaltensilestrengthandelasticmodulus theuseofnanoreinforcementsinpolymercompositeshaspro conventional unidirectional polymer composite micron duced unprecedented improvement mechanical property size fiber reinforcement excellent corresponding thecomposites koratkaretal 22 measuredgreaterthan1000 matrix dominated transverse tensile strength longitudinal increase fig 2 inthelossmodulusofpolycarbonate pc without compressive strength property often poor however significantreductionsinthestoragemoduluswhenthepcwasen traditionallypoorpropertiescanbesignificantlyimprovedby hanced 2wt single walled carbon nanotube swnts replacingtheneatresinpolymermatrixwithananocompositema washypothesizedthatfrictionalslidingattheswnt pcinterfaces trix see fig 3 vlasveld et al 29 b growing wasthereasonfortheenhancedenergydissipation thishypothe nanoreinforcementslikecarbonnanotubesonthesurfaceofthefi sisissupportedbytheanalysisofzhouetal 23 whodevelopeda bers seefig 4fromzhaoetal 30 model frictional sliding damping mechanism based one example approach uddin sun 31 reported interfacial stick slip frictional motion nanotube silica nanoparticle enhanced epoxy used andthepolymermatrix rajoriaandjalili 24 reportedthatmul matrix material unidirectional e glass epoxy composite ti walled carbon nanotube mwnts effective longitudinalcompressivestrengthandmoduluswerebothsignifi swntsinimprovingdampingofepoxy buttherewasnosignifi cantly improved minimization particle agglomeration cant effect storage modulus another way incorporate resultingimproveddispersionofsilicananoparticlesintheepoxy improved damping associated nanotube reinforcement matrix due use sol gel process based use istoembednano enhancedpolymerfilmsub layerswithinamul organosilicasol colloidal silica organic solvent believed tifunctionalcompositelaminate 25 26 betheprimaryreasonfortheimprovements morerecentresearch bymixingsilicamicroparticlesandepoxyintherightpropor thesame author extendedthe approachtohybrid multiscale tions itispossibletosimultaneouslyincreasestrengthandmodu composite containing silica nanoparticles lu resulting composite reducing coefficient sol gel process alumina nanoparticles carbon nanofibers2796 r f gibson compositestructures92 2010 2793 2810 fig 5 flexuralmoduliofdifferentnanocompositesatvariousparticleloadings reprintedfrom 32 withpermissionfromelsevier fig 3 nanoparticlereinforcementofthematrixinaunidirectionalfibercomposite reprintedfrom 29 withpermissionfromelsevier fig 6 flexuralstrengthsofdifferentnanocompositesatvariousparticleloadings reprintedfrom 32 withpermissionfromelsevier fig 4 multi walled carbon nanotube grown surface carbon fiber reprintedfrom 30 withpermissionfromelsevier cnf inanepoxymatrix 32 asshowninfigs 5 7 simultaneous improvement least 30 modulus strength strain breakarepossiblewithseveraltypesofthesehybridnanocompos ites similarly liu et al 33 zhang et al 34 found young smodulus tensilestrengthandfracturetoughnessofepoxy simultaneously improved addition sol gel formed nanosilica particle dispersion particle excellent manjunatha et al 35 observed addition 10wt sol gel formednanosilicatotheepoxymatrixresultedin simultaneous improvement 4 4 tensile strength 7 4 tensilemodulusandafactorof2 3intensilefatiguelifeofaglass fabric reinforcedepoxycomposite thepresenceofthenanoparti fig 7 flexural strain break different nanocomposites various particle cleswasbelievedtosuppressmatrixcrackingandreducedelami loading reprintedfrom 32 withpermissionfromelsevier nation growth rate thus improving fatigue life since hybrid multiscale composite typicallyhave reinforcement size ranging decreasingparticle size micronand nano range long micron scale nano scale essential asparticleagglomerationwasavoided choandsun 37 laterused standtheeffectsofparticlesizeontheresultingcompositeproper moleculardynamicssimulationtoshowthatifthepolymer nano tie importantobservationsregardingsucheffectswerereported particleinteractionstrengthisgreaterthanthepolymer polymer bychoetal 36 whomeasuredmodulusandstrengthofvinyles interactionstrength thepolymerdensitynearthepolymer nano terpolymermatrixcompositescontainingsphericalaluminaparti particleinterfaceandtheyoung smodulusofthenanocomposite clesorglassbeads withparticlesizesrangingfrom0 5mmdown increase significantly reduced particle size to15nm itwasfoundthattheyoung smoduluswasnotaffected search needed particle size effect structural varying particle size micron range particle andnon structuralpropertiesofnanocompositesandhybridmul sizewasreducedinthenanorange theyoung smodulusincreased tiscalecomposites thisisparticularlytrueforanalyticalmodeling withdecreasingparticle size tensilestrength increased sincemostofthepublicationstodateinvolveexperimentalwork r f gibson compositestructures92 2010 2793 2810 2797 fig 8 useofalignedcntforeststostrengtheninterlaminarregionincompositelaminates reprintedfrom 41 withpermissionfromelsevier approach b involves growth nanotube important non structural function including electrical surfacesofmicron sizedfibershasalsobeenthesubjectofnumer thermal conductivity sensing actuation energy harvesting ous investigation thostensonet al 38 grew carbonnanotubes storage self healing capability electromagnetic interference cnts onthesurfaceofcarbonfibersusingchemicalvapordepo emi shielding recyclabilityandbiodegradability sition cvd thenconductedsinglefiberfragmentationtestsofthe modifiedcarbonfibersinanepoxymatrixtodeterminethefiber 3 1 electricaland orthermalconductivity matrixinterfacialshearstrength itwasfoundthattheinterfacial shearstrengthofthemodifiedcarbonfiberswas15 greaterthan among important non structural function thatofthebaselinecarbonfibers veeduetal 39 alsousedcvdto structure may need electrical thermal conductivity growalignedcntforestsperpendiculartothesurfaceof2dwoven themostwidelyusedcompositeshavepolymermatrixmaterials sic fabric cloth consisting micron size sic fiber fabric whicharetypicallypoorconductors oneveryimportantapplica infiltrated epoxy resin stacked form 3d tion polymer composite electrical conductivity composite compared baseline composite 3d com quired aircraft structure non conducting structure positewasfoundtoexhibitsimultaneousandsignificantimprove may damaged lightning strike conductive polymer mentsinthemodeiandmodeiifracturetoughnesses theflexural nanocomposites investigated possible replacement modulus theflexuralstrength theflexural toughness coeffi non conducting polymer matrix material would elimi cientofthermalexpansion thethermalconductivityandtheelec natetheneedforadd onmetallicconductors whicharetooheavy trical conductivity true multifunctional composite andmaybedifficulttorepair 45 enhancedthermalconductivity combiningstructuralandnon structuralfunctions andwillbedis composite important cooling electronic circuit cussedfurtherinthenextsection furtherstudiesandapplications propulsionsystems thestructuraladvantagesofnanocomposites ofalignedcntforeststoconventionalfibercompositeshavebeen havealreadybeensummarizedinthepreviussection andthere reported wardle colleague 40 44 focused abundant evidence literature simultaneous improve theuseofthealignedcntforeststoimproveinterlaminarstrength ments mechanical electricalproperties nanocomposites andtoughness thesearemajorconcernsaboutconventionalcom 46 49 positelaminatesbecauseoftheweakmatrixresin richregionsthat itturnsoutthatverysmallconcentrationsofcarbonnanotubes existbetweenthecompositelaminae asshowninfig 8 vertically conducting nanoreinforcements polymerslead dis alignedcntforestscanbridgeandstrengthenthisinterlaminarre proportionatelylargeimprovementsintheelectricalconductivity gion 41 specifically author reported cnt ofthenanocomposite forexample fig 10showsthattheelectri modified interface increased mode interlaminar fracture calconductivityofcnt epoxynanocompositesincreasesbynearly toughnessofaerospacegradecarbon epoxylaminatesbyafactor 6decadeswhenthecntconcentrationisincreasedbyonly2dec 1 5 2 5 corresponding mode ii value factor 3 ade 9 percolationthreshold u whichisthecntconcen c analytical modeling fracture toughness cnt modified trationinthepolymerthatcharacterizestheinsulator conductor laminatesbasedonthecrackclosuretechniqueforfiberbridging transition 0 04wt case percolation theory accu wasreportedlaterin 43 theso called fuzzyfiber cntsgrown ratelydescribesthistransitionbyequation oncarbonfibers conceptappliedtocompositelaminatescanpro k ¼ðu cid 2 u þa ð1þ vide interlaminar intralaminar reinforcement illus c c tratedinfig 9 44 sandleretal 50 reportedultra lowpercolationthresholdsas low 0 0025wt aligned mwnt epoxy nanocomposites 3 integratedstructuralandnon structuralfunctions percolation threshold cnts polymer matrix material issolowbecausetheextremelyhighaspectratiosofcntsmake indicated previous section development relativelyeasyfor contiguous conductingpath percolation nanocompositesandhybridmultiscalecompositescontainingboth networktoformalongthetangledcntsintheinsulatingpolymer conventional micron level reinforcement nano level rein matrix fig 11fromlietal 51 showshowthepercolationthresh forcementshasmadeitpossibletoachievesimultaneousimprove old decrease increasing cnt aspect ratio since processing ments multiple structural function multiple typicallybreaksupcntsintoshorterlengths itisimportanttode non structural function well section focus several velopprocesseswhichpreservethehighaspectratiosofcnts thus2798 r f gibson compositestructures92 2010 2793 2810 fig 9 illustrationoffuzzyfiberreinforcedplastic ffrp radiallyalignedcntsgrownonadvancedfibercloth b cntintralaminarandinterlaminarreinforcement reprintedfrom 44 withpermissionfromelsevier fig 11 effectofcntaspectratioonpercolationthresholdforcntnanocomposites varying dispersion state copyright wiley vch verlag gmbh co kgaa reproducedfrom 51 withpermission thecntsarestraight theimportanceofwavinesswasconfirmed fig 10 electrical conductivity cnt epoxy nanocomposites various cnt li etal 53 whoused monte carlosimulationsto showthat concentration percolation threshold 0 04wt reprinted 9 theelectricalconductivityofcompositeswithwavynanotubes permissionfromelsevier lessthanthatofcompositeswithstraightnanotubes insuringthedesiredlowpercolationthresholds thostensonetal although thermal conductivity cnt polymer nanocom 52 reportedthata3 rollmillprocessinducesintenseshearmix posites increase increasing cnt concentration ingofacnt vinylesternanocompositewhilepreservingthehigh crease gradual sharp insulator conductor aspect ratio cnts photomicrograph show cnts transition percolation threshold electrical conductivity wavy butmostanalyticalmodelsarebasedontheassumptionthat 54 accordingto shenoginaet al 54 thedifference lie ther f gibson compositestructures92 2010 2793 2810 2799 conductivityratiok k forthermaltransport evenforverycon andthecorrespondingpiezoelectriccouplingcoefficientforconver f ductive highaspectratiocnts k k isonlyabout104 butforelec sionofelectricalenergytomechanicalenergy e foractuation f trical transport k f k much 1012 1016 result sffiffiffiffiffiffiffiffiffiffiffiffi electricaltransportisdominatedbythepercolatingcntnetwork ka¼ w ð3þ whereas thermal transport strongly influenced polymer u e matrix althoughthereisalackofapercolationthresholdforther themostwidelyusedformsofpiezoelectricmaterialsarewa mal conductivity cnt polymer composite small amount fers 61 andthinfilms 62 andnumerouspublicationshavedealt cntsstillleadtodisproportionateincreasesincompositethermal withthemovermanyyears piezoelectricmicroelectromechanical conductivity example biercuk et al 55 found 1wt system mem forsensingandactuationhavebeenthesubjectof swntsinepoxyresultedina125 increaseinthermalconductiv extensive research state art area ity room temperature bonnet et al 56 measured 55 veryrecentlyreviewedbytadigadapaandmateti 63 soinorder increase thermal conductivity 7wt swnt pmma com avoid duplication focus important recent posite andkimetal 57 reporteda57 increaseinthermalcon development structurally integrated sensing actuation ductivity adding 7wt mwnts phenolic resin however load bearingmultifunctionalcompositestructures since higher filler loading required create significant althoughnotascommonaspiezoelectricwafersorthinfilms improvementsinthermalconductivityofpolymers thismaylead piezoelectric fiber investigated possible active toprocessingissues forexample gangulietal 58 wereableto component multifunctional fiber reinforced composite achievea28 foldincreaseinthermalconductivityofepoxybyadd earliestreportsofpiezoelectricfibercomposites pfc wereappar ing 20wt chemically functionalized exfoliated graphite entlypublishedbyhagoodandbent 64 andbentetal 65 flake butgraphiteloadinglevelsgreaterthan4wt werefound embeddedmicronsizedpiezoelectricfibersinanepoxymatrixto toincreasetheviscosityofthemixturebeyondthedesirablepro pzt powder added reduce fiber matrix cessing window vacuum assisted resin transfer molding dielectricmismatch thepfclaminatewasbuiltupfrompfclam vartm process application small amount inaeembeddedbetweenconventionalgraphite epoxylaminaeand cntsareneededtoproduceacceptablethermalconductivity interlaminar electrode applied electric field required example sihnetal 59 foundthatthethrough thicknessthermal actuation good agreement obtained measured conductivityofepoxyadhesivejointscanbeincreasedbyseveral electrically induceddeformationsandthosepredictedbyamodi ordersofmagnitudewhenalignedmwnt nanograss isincorpo fiedclassicallaminationtheorywhichincludedactuator induced ratedintheepoxyadhesive fig 12 stressterms 65 morerecentlydevelopedhollowpiezoelectricfi bers 66 67 offertheadvantageofloweroperatingvoltageanda 3 2 sensingandactuation broader choice possible matrix material compared solid cross section piezoelectric fiber brei cannon 67 investi sensing actuation two closely related non structural gatedthehollowpiezoelectricfiberconceptinfig 13 withempha function andinmanycases thesamematerialordevicecanbe si effect three key design parameter matrix fiber usedforbothfunctions aswellasforotherfunctionslikeenergy young 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 manufacturingandreliabilityoftheactivecomposites infig 13 search related sensor actuator used actuation mode radial poling piezoelectric fiber multifunctional structure example li et al 6 gibson sultsinlongitudinaldeformationofthefiber whileinthesensing et al 7 reviewed recent research related sensor mode longitudinaldeformationresultsinradialelectricaloutput actuatorsbasedoncarbonnanotubesandtheircomposites stillmorerecently linandsodano 68 69 developedpiezoelectric viewarticlebyratnaandkarger kocsis 18 coversrecentresearch structuralfibersconsistingofconductivestructuralfiberssuchas onshapememorypolymerswhichhavepotentialapplicationsas sensorsand oractuators piezoelectric materialssuchasleadzir conate titanate pzt polyvinylidene fluoride pvdf alumi numnitride aln canbeembeddedinstructuresforsensingand actuation astheynaturallypossesstherequiredelectromechanical coupling effectiveness piezoelectric material convert applied mechanical energy electrical energy e sensingorenergyharvesting ischaracterizedbythepiezoelectric couplingcoefficient 60 sffiffiffiffiffiffiffiffiffiffiffiffiffi u k ¼ e ð2þ w fig 12 nanograss enhancedpolymeradhesivejointforimprovedthrough thick fig 13 hollowpiezoelectricfiberwithradialpolingandlongitudinalactuationof nessthermalconductivity reprintedfrom 59 withpermissionfromelsevier thefiber reprintedfrom 67 withpermissionfromelsevier 2800 r f gibson compositestructures92 2010 2793 2810 indicated earlier several recent review article dealt withthegeneralareaofstructuralhealthmonitoring 11 14 focus specifically use embedded piezoelectric sensor actuator network damage detection composite structuresduetoitsimportanceinthedevelopmentofmultifunc tionalstructures linandchang 71 describedthefabricationand initial validation testing stanford multi actuator receiver transduction smart layer cid 3 concept fig 16 concept volvestheuseofprintedcircuittechnologytoproduceathinflex ible dielectric film array networked piezoceramic actuator sensor whichisembeddedwithinaconventionalcom positelaminate itwasshownthataconventionalautoclavepro ce cure cycle used fabricate carbon epoxy compositelaminatescontainingthesmartlayer cid 3 thatthelayer doesnotsignificantlydegradethemechanicalbehaviorofthecom posite

andthatbymeasuringthephasedelaybetweenthetrans
mittedandreceivedstresswaveduringthecureprocess thestate fig 14 multifunctional piezoelectric
structural fiber reprinted 68 permissionfromelsevier cure monitored subsequent research 72 showed
suchlayerscanbeintegratedintocompositestructuresfabricated byrtmandfilamentwindingprocesses
andthattheconceptcan carbon coated piezoelectric interphase layer outer
beappliedtoeitheractiveorpassivesensingtomonitorthehealth electrodelayer fig 14
aswiththehollowpiezoelectricfiberin structure throughout lifetime still recently wu fig 13 radial
polingresults longitudinal actuationofthefiber et al 73 demonstrated feasibility improved actuator forth
finite element model piezoelectric structural fi sensor network damage detection composite laminate
ber polymermatrixcompositessuchastheoneinfig 15showed
basedontheuseofpztactuatorsandfiberbragggrating fbg fi electromechanical coupling coefficient
available beropticsensorsinsteadofusingpztsforbothactuatingandsens composite high 65 70
corresponding ing advantage approach lie decoupling couplingcoefficientforthefiberitself
andthatpiezoelectricstruc signal transmission mechanism elimination signal
turalfibercompositesaresuitableforvibrationcontrol damping crosstalk actuator sensor signal pzt actua
energyharvestingorstructuralhealthmonitoring tor sensor network approach active sensor network
thecapabilityofsimultaneouscontrolofstiffnessanddamping
fordamagedetectionincompositestructureshavebeenreported
isasignificantadvantageofanewclassofmaterialsknownasmag bysuetal 74 75
reportsontheuseofartificialneuralnetworks netorheological elastomer mre consist conventional analyze
data piezoelectric sensor network elastomer filled micron sized magnetizable particle
classifyandlocatethedamageincompositestructureshavebeen asiron asreportedbyfuchsetal 70
anappliedmagneticfield published watkins et al 76 haywood et al 77 yu
ofvariablestrengthwasusedtocontinuouslyandrapidlycontrol etal 78
similarsystemshavebeenadaptedforcontrolofsmart
stiffnessanddampingofapolybutadieneelastomerfilledwith3 laminatedstructuresbysrivastavaetal 79 7lm
diameter carbonyl iron particle case optimum layer layer lbl assembly whichinvolvessequentialdepo
concentration iron particle greatest improvement sitionofdissimilarthinfilmsatthenanoscale
hasmadeitpossible dampingandstiffnesswasfoundtobe60wt andotherimportant
todevelopsensorsthatarecapableofdetectingmultiplephenom
variableswhichgovernthestiffnessanddampingofmresarethe ena forexample lohetal 80
usedthelblmethodtofabricatea alignmentofthemagneticparticlesandthetemperature carbon nanotube
polyelectrolyte multilayer composite material fig 15
finiteelementmodelofpiezoelectricstructuralfiberembeddedinapolymermatrix reprintedfrom 68
withpermissionfromelsevier r f gibson compositestructures92 2010 2793 2810 2801 fig 16 stanford
multi actuator receiver transduction smart layerconceptofintegratedsensor
actuatornetworkinacompositelaminate reprintedfrom 71 permissionfromelsevier
formonitoringstrainandcorrosion inthiscase theconcentration
themostcommonmodeofenergyharvestinginvolvestheuse carbon nanotube determines sensitivity strain
piezoelectric material convert mechanical deformation
typeofpolyelectrolytedeterminesthesensitivitytoph deposition
fromvibratingstructuressuchasbeamsandplatestoelectricalen
ofsuchalblsensoronaminiatureplanarcoilantennaresultsina ergy itappearsthatsodanoetal 84
werethefirsttoreportthat passive wireless sensor require battery power
thepoweroutputfromarandomlyvibratingpiezoelectricmaterial supply 81 lbl method also used fabricate
high iscapableofrechargingadischargednickelmetalhydridebattery
strengthmultifunctionalcompositesforbiologicalimplants anti
theyalsoreportedontheuseofthepiezoelectricoutputtocharge corrosion coating thermal electrical
interface material capacitor concluded capacitor discharge occurred 82 83 shape memory polymer also
great potential tooquicklyforpracticalenergystorageandthatbatteriesprovided useinsensorsandactuators
thisisparticularlytrueforelectroac moreflexibilityinuseofthestoredenergy
tiveshapememorypolymercompositescontainingconductivefill inamultifunctionalstructure
thebatteryshouldbecomepartof er 18 theload bearingstructure pereiraetal 85 86 embeddedthinfilm

lithiumenergycellswithincarbon epoxylaminatestoformenergy 3 3 energyharvesting storage storagestructuralcomposites thelithiumenergycellsdidnotsig nificantly change strength stiffness carbon epoxy basic idea behind energy harvesting storage related laminate energy cell charged discharged normally multifunctional structure parasitically extract energy whenthecompositewasmechanicallyloadedtoashighas50 themotionand ordeformationofahoststructureand convertit itsultimatetensilestrength furtherintegrationwas achievedby electrical energy stored used pur kimetal 87 whousedacoppernano inkjet printedcircuiton pose onepopularapplicationistopowersmallelectronicdevices polymer film interconnect thin film solar module suchaswirelesssensorsforstructuralhealthmonitoring several thin film lithium ion battery resulting film embedded review article already published subject 14 co cured within carbon epoxy prepreg layer fabricate 17 andsincethediscussionofsensorsandactuatorsintheprevi energyharvesting storagelaminate themultifunctionallaminate oussectionisalsohighlyrelevanttoenergyharvesting theempha subjected mechanical loading shown fig 17 sisinthissectionwillbeonrecentdevelopmentsinenergystorage ink jet printed electrode thicker 4lm inload bearingmultifunctionalstructures exhibit significant resistance change maxi fig 17 resistanceofinkjet printed160lm wideelectrodeunderstaticloadingforseveralelectrodethicknesses resistanceand b percentageofresistancechange reprintedfrom 87 withpermissionfromelsevier 2802 r f gibson compositestructures92 2010 2793 2810 mum strain 1 liu et al 88 developed new load bearing structuralbatteryinwhichthepolymercathodeinaconventional polymer lithium ion battery fig 18 replaced higher molecular weight carbon nanofiber reinforced polymer fig 19 theorganicliquidelectrolytewasreplacedwithasolid statepoly merelectrolyteandtheseparatorregionwasreinforcedwithnon conductingfibers althoughthisdesignrepresentsastartingpoint thetensilemodulusofthebatterywasonlyabout3gpa andthe energydensitywaslowcomparedwiththatofaconventionallith ium ion battery work needed develop usable structuralbattery snyderetal 89 investigateddifferentpolymer electrolyte formulation multifunctional structural battery ranging highly conductive structurally weak poorly conductiveandhighlystructural asshowninfig 20 itwasfound thattheelectricalconductivityandtheelasticmodulusofthedif ferentformulationsareinverselyrelated whichmakesitdifficult tooptimizebothproperties inaseparatepaper snyderetal 90 investigatedthepropertiesofcommercialcarbonfabricmaterials carbonnanotubepapersandnanofoampapersforpossibleuseas fig 20 experimentaldatashowinginverserelationshipbetweenelectricalcon anode multifunctional lithium ion battery im 7 t300 ductivity compressive modulus several polymer electrolyte use pan basedcarbonfabricsyieldedthebestbalancebetweenelectro structuralbatteries reprintedfrom 89 withpermission copyright2007american chemicalsociety chemical tensile strength performance whereas pitch based fabric exhibited poor multifunctional performance nanofoam paper best electrochemical performance grated capacitor provide energy storage quick discharge themechanicalpropertieswerepoor athighenergylevels brienetal 91 comparedstiffnessanden althoughstructuralintegratedbatteriesare morepracticalfor ergydensityofvariousstructuralcapacitors asshowninfig 21 slower discharge longer period time structurally inte conventionalcapacitorshavehighenergydensitybutpoorstiffness fig 18 constructionofconventionalnon structuralpolymerlithium ionbattery reprintedfrom 88 withpermissionfromelsevier fig 19 constructionofnewstructuralbattery reprintedfrom 88 withpermissionfromelsevier r f gibson compositestructures92 2010 2793 2810 2803 fig 21 energydensityandspecificmodulusofmultifunctionalstructuralcapac itors dashedlinerepresentsdesigngoalfortruemultifunctionality reprintedfrom 91 bypermissionofthesocietyfortheadvancementofmaterialandprocess engineering sample whereasstructuralcompositeshavegoodstiffnessbutpoorenergy density noneofthematerialsevaluatedmetthedesigngoalofmul tifunctionalefficiencyforsystemlevelweightsavingsshownbythe fig 22 illustration self healing crack polymer use dashedlineinfig 21 inacontinuationofthiswork baechleetal microencapsulatedhealingagentandacatalystforpolymerizingthehealingagent 92 addressed design issue improving multifunctional effi reprintedfrom 96 withkindpermissionfromspringerscience businessmedia ciencyandscalingissuesrelatedtomanufacturing luoandchung 93 developed high capacitance structural capacitor consisting research optimization microcapsule concen carbon epoxy laminate paper interlayer reduce tration choice catalyst led crack healing efficiency thickness conductivity capacitor over90 g 0 9 inself healedspecimensandmaximumhealing mechanicallytested linandsodano 94 demonstratedthattheir efficiencywasachievedwithin10hofthefractureevent 96 still previouslydevelopedsic batio piezoelectricstructuralfiber 69 morerecently carusoetal 97 obtainedcompleterecoveryofvir 3 couldbeusedasastructuralcapacitorbytakingadvantageofthe gin fracture toughness g 1 replacing original solvent dielectricnatureofthebatio coatingonthesicfiber e theba healingagentinthemicrocapsuleswithepoxy solventmicrocap 3 tio coatingwasemployedasacylindricalcapacitor fiberswith sules containing mixture epoxy monomer solvent 3 anaspectratioof0 23werefoundtobethebestforenergystorage showninfig 23b theresultingload displacementcurvesindicate fullrecoveryofvirginfracturetoughness relatedresearchbythe 3 4 self healingcapability group considered self healing polymer fatigue loading 98 100 low velocity impact loading 101 well atrulyautonomousmultifunctionalstructurewillbecapableof development self healing polymer coating provide healingitselfwhendamaged asabiologicalsystemwould andre effective corrosion protection steel substrate 102 cent research demonstrated feasibility material useofthree dimensionalmicrovascularnetworksinthesubstrate particularlypolymericmaterials acomprehensivereviewofpub beneathanepoxycoatingtoenablecontinuousdeliveryofhealing 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 otherrecentdevelopmentsinself healingpolymercomposites polymersandpolymercompositesbasedontheuseofamicroen includetheuseofdifferentmethodsofhealingagentmicroencap capsulatedhealingagentandacatalystforpolymerizingtheheal sulationsuchasnanoporoussilicacapsules 104 andnanoporous ingagent asshowninfig 22 whendamagecausescracksinthe glass fiber 105 use self healing polymer matrix polymer crack break open microcapsules causing materialincarbonfiber reinforcedcompositeshasalsobeencon healingagenttoleakintothecrackbycapillaryaction thehealing 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 ofvirginepoxyandself healedepoxyspecimensusingthetapered likely cause believed time dependent diffusion double cantileverbeam tdcb test fig 23a showed thatfrac epoxymonomerfromthe microcapsules followingcontractionof tureloadandcorrespondingfracturetoughnessfortheself healed microcapsules cure process degradation specimensreachedupto75 ofthecorrespondingvaluesforthe foundto self limiting process leaked epoxygradually virgin uncracked specimen crack healing efficiency curedandblockedthediffusionsitesonthemicrocapsules butit fracturetoughnesstestisdefinedas concluded research needed improve microcapsuledesignsandmaterials k p g¼ ichealed ¼ chealed ð4þ mostoftheresearchon self healing materialshas beenbased k p icvirgin cvirgin onexperimentalwork andonlyafewpublicationshavedealtwith2804 r f gibson compositestructures92 2010 2793 2810 fig 23 load displacementcurvesformodeifracturetoughnesstestsofvirginandself healedspecimens microcapsulescontainsolventhealingagentonly reprinted 95 bypermissionfrommacmillanpublishersltd b microcapsulescontainamixtureofepoxymonomerandsolventcopyrightwiley vchverlaggmbh co kgaa reproducedfrom 97 withpermission analytical modeling self healing process balazs 108 whenusedasmatrixmaterialsinmultifunctionalfibercomposite brieflyreviewedcomputationalmodelsforself healingmaterials structuresisnotclear however blendsoficpssuchaspaniwith whilepointingoutthattheareaisstillinitsinfancyandthatsolu established structural polymer like epoxy resin may tions require development multidisciplinary method practical approach jia et al 116 studied electrical conductivity involvingmodelsforfluiddynamics structuralmechanics chemi pani epoxy composite different pani morphology calreactivity andphasetransitions barberoetal 109 haveap asshowninfig 24 thecompositescontainingpaniwireshada plied principle continuum damage mechanic case lowerpercolationthresholdthanthecompositescontainingpani 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

usedaconventionalcurekineticsmodelandelectricalresis catedinsection3 1
theuseofotherhighaspectratioelectrically tance heating polymer matrix glass transition conducting
nanofillers polymer also effective mean temperature achieve self healing carbon fiber mendomer
creatingelectricallyconductingpolymercomposites whichinturn composite suitable emi shielding
example huang et al 117 al saleh sundararaj 118 investigated
emishieldingcharacteristicsofcarbonnanotube polymercompos 3 5 electromagneticinterference emi
shielding ites whiletheemishieldingpropertiesofcarbonnanofiber poly
mercompositeshavebeenstudiedbyyangetal 119 areview electromagneticinterference emi
occurswhenanundesirable ofrecentarticlesonconductivityandemishieldingcharacteristics disturbance
due electromagnetic conduction radiation vapor grown carbon nanofiber polymer composite
anexternalsourceinterfereswiththeoperationofanelectricalcir publishedbyal salehandsundararaj 120 cuit
theusualsolutiontoemiistoprotectthecircuitwithanemi shieldingmaterialorstructure
andtheshieldingeffectiveness se isdefinedindecibels db e h se¼20log t¼20log ð5þ e h
electricallyconductingmetallicmaterialshaveexcellentse
duetoreducedweightandotherdesirableproperties non metallic material polymer polymer composite
increas inglyusedtoreplacemetals seisparticularlyimportantformul
tifunctionalmaterialsandstructureswhicharetypicallybasedon polymer composite electrical mechanical
function typically involved order achieve acceptable se
thepolymermustbeeitheranintrinsicallyconductingpolymer icp
orbefilledwithaconductingmaterialsuchascarbonfibers nanotube coated conductive coating several
centreviewarticleshavediscussedvariousaspectsofemishield ing especially polymer chung 113 reviewed
publication onmaterialsforemi geethaetal 114 surveyedrecentresearch onmethodsandmaterialsforemi
whilewangandjing 115 viewedarticlesdealingwithicpsforemi fig 24 electrical conductivity pani epoxy
composite different pani whileicpssuchaspolyaniline pani andpolypyrrole ppy
contentsanddifferentpanimorphologies paniparticles b panifibers effective emi shielding mechanical
effectiveness c paniwires reprintedfrom 116 withpermissionfromelsevier r f gibson
compositestructures92 2010 2793 2810 2805 3 6 recyclabilityandbiodegradability
requirementsinthedesignofmultifunctionalcomposites andthis
makesoptimizationofsuchsystemsanevengreaterchallenge
associetalconcernsaboutenvironmentalimpact sustainability
andrenewableenergysourceshaveincreasedinrecentyears recy 4
recentapplicationsofmultifunctionalmaterialsand clability biodegradability taken correspondingly
structure importantrolesasnon structuralfunctionsofadvancedmaterials particularly true polymer polymer
composite much research multifunctional material struc nanocomposites
theseareveryactiveresearchareas andanum
tureshasbeendrivenbycurrentandpotentialaerospaceapplica
berofrelevantreviewarticleshavealreadybeenpublishedabout tions example motivated primarily potential
aircraft subject objective limited providing
applicationsandbytechnologicaladvancesincompositematerials
briefoverviewsofrepresentativereviewarticles sensing actuation control ability multifunctional
henshawetal 121 pickering 122 ramakrishnaetal 123 structuretoreconfigure
ormorphitselfasitsoperatingenviron vaidya chawla 124 derosa et al 125 reviewed mentand
oritsmissionprofilechangeshasbeenasubjectofgreat publication dealing various recycling issue polymer
researchinterestinrecentyears onemajorgoalofsuchresearchis composite material due faster simpler
processing cycle todevelopmultifunctionalaircraftwingswhichcanchangeshape forthermoplasticpolymers
recyclingofthermoplasticcomposites indifferentphasesofflightasabirdwingdoes amajorapplication
process injection compression molding new ofthesetechnologiesisformorphingaircraftskins andacompre
compositesiseasierthanfor thermosetmatrix composite hensive review publicationson morphing skin
pub likely recyclingscenarios thermoset matrix composite lished recently thill et al 143 since publication
eithermechanicallyrecyclethembygrindingthemintosmallpar reviewarticle severalrelevantapplications
orientedpublications ticles using filler new composite ther appeared example wildschek et al 144
reported mally recycle using intense heat break thedevelopmentofanall composite
electricmorphingtrailing composite reusable component possible loss mechanical

edgeforflightcontrolonablendedwingbodyairliner hartletal property recycling significant issue method 145 146 describedtheuseofashapememoryalloyforactivejet improving property mechanically recycled thermoplastic enginechevronapplications andmudupuetal 147 discussedthe described tall et al 126 recycling composite designandvalidationofafuzzylogiccontrollerandapiezoelectric containingnanoparticles nanofibersornanotubesandothernano compositeactuatorforasmartprojectilefin wasterequiresspecialconsiderationduetopotentialtoxicity car structurallyintegratedbatteriesforenergystorageareanother cinogenicity andotherhealth relatedconcerns asdiscussedinthe recent application multifunctional structure design effec reviewarticlebybystrzejewski piotrowskaetal 127 tiveness multifunctional system best defined using ifacompositeistobebiodegradable naturalfibersandpolymer metric characterizes particular system flight matrixmaterialsmadefromrenewableresourcesareobviouslyof endurance time aircraft vehicle example reported greatinterest researchonnaturalfiberssuchas jute ramie flax bythomasandqidwai 148 149 structurallyintegratedbatteries 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 yanetal 131 eichhornetal 132 andcheungetal 133 typ uavisgivenby 148 149 ically thestrengthandmodulusvaluesfornaturalfibersarewell conventional structural fiber glass e g qsc3 1 2 ¼ b b l g ð6þ due low density specific modulus natural fiber e ðw þw þw þw þ3 2 2c2 p b pr pl areasgoodorbetterthanthatofglass publicationsdealingwith thedevelopmentofpolymersfromrenewableresourceshavebeen thisequationshowsthatintegratingthebatterywiththestruc surveyed yu et al 134 raquez et al 135 test tureoroneoftheothersubsystemscanleadtoanincreasedflight methodsforcharacterizingbiodegradabilityofpolymericmaterials endurancetime e furtheranalysisofthisequationforchangein reviewed gu gu 136 natural protein based e change battery structure weight show material received considerable attention biomedical decreasingtheweightis1 5timesmoreeffectiveinincreasingt e application indicated kumar et al 137 biodegradable thanisincreasingthebatteryenergy 148 byintegratingapoly bio based green nanocomposites consistingof matrix material merlithium ionbatteryinthecarbon epoxycompositewingskin cellulosic plastic corn derived plastic plastic made structure darpa wasp micro air vehicle mav record frombacterialsourcesreinforcedbynanoclayparticleshavebeen setting flight endurance time vehicle achieved 149 subject extensive recent research reviewed pandey aphotoofthisvehicleisshowninfig 25 etal 138 andrayandbousmina 139 onedrawbackto green anotherexampleofmultifunctionalstructuretechnologythatis compositesisthattheirmechanicalpropertiesaretypicallymore drivenbyaerospaceapplicationsistheintegrationofanelectronic sensitive hygrothermal condition conventional communication antenna load bearing composite struc composite forexample absorbedmoisturehasbeenfoundtosig ture aircraft conformal load bearing antenna structure nificantly degrade mechanical property hemp fiber com clas developmenteffortsponsoredbytheusairforce ssmart posites 140 flax fiber composite strongly affected skinstructuretechnologydemonstration s3td programintends elevated temperature 141 however special chemical treat todevelopthetechnologytoembedabroadbandrfantennainto mentsfornaturalfiberscanreducetheirsensitivitytohygrother thecompositeskinofafighteraircraft 150 153 morerecentre malconditions 142 searchrelatedtotheclashasinvolvedthedesignandfabrication publication listed far involve experimental ofamicrostripantennawhichisintegratedinathreedimensional work andthereisaneedfordevelopmentofmoreanalyticalmod orthogonal woven composite structure 154 impact testing elstocomplimenttheexperiments analyticalmodelsareneeded thesestructures 155 andwirelessdetectionofdamageincom help interpreting experimental result posite structure making use composite structure optimizing multifunctional material system specific asanantenna sensorsystem 156 application obviously thereareotherissuessuchashygrother compositesandwichstructurespresentsomeinterestingpossi mal response sound absorption may become functional bilities multifunctional application example wirtz et al 2806 r f gibson compositestructures92 2010 2793 2810 fig 26 recentenglishlanguagerefereedjournalarticlesrelatedtomultifunctional nanoparticles data collected engineering village cid 2 web based information service havereviewedtheliteratureintheareaofpolymernanocomposite foam fig 25 firstgenerationdarpawaspmicroairvehiclewithpolymerlithium ion among challenging promising application battery silver quadrilateral integrated composite wing skin structure reprintedfrom 149 withkindpermissionfromspringerscience businessmedia multifunctionalmaterialsandstructuresarethoseinthebiomed ical 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 antibodydeliveryincombinationwithdiagnosticsandthera multifunctional structure thermal interface connected peutics since2000therehasbeenasurgeinthenumberofjournal toahollowaluminumplatewhichhasaseriesofsmallcompart articlesrelatedtomultifunctionalnanoparticles asshownclearly mentsthat filledwithphase changematerial heatstorage infig 26 suhetal 164 havereviewedthedevelopmentsinmul viathelatentheatofthephasechangematerial thethermalen tifunctionalnanoparticlesystems mfnps forbiomedicalapplica ergystorageandmechanicalbehaviorofthestructurearecharac tions fig 27 illustrates one possible configuration terized determined structure excellent mfnps thematrixofthemfnpscouldbeametaloxidenetwork performance weight ratio queheillalt et al 158 developed host sub domain inclusion fluorescent optical multifunctional heat pipe sandwich structure integrates probe magneticallysusceptibleparticlesformagneticresonance thethermalmanagementcapabilitiesofaheatpipewithstructural imaging andporesorfunctionalitieswhichcanhostsmallbioac loadsupport ozakietal 159 reportedonmultifunctionalsand tivemoleculessuchasdrugsorantibodies inclusionscanbeeither wich panel space satellite electronic module organic inorganicorhybridorganic inorganic 164 abionanoen embeddedbetweenthefacesheetsofcarbonfibercomposite hon gineering design process multilayered mfnps described eycombcoresandwichpanel themechanical electricalandther haglundetal 165 andsuchamultilayeredparticleisillustrated mal characteristic panel evaluated significant infig 28 mfnpsoffergreathopeforearlydetectionofcancerand reduction weight cost production time achieved deliveryoftherapeuticdrugsforcancertreatment publicationsre use carbon foam core carbon fiber composite face latedtothedevelopmentofmfnpsforcancerimagingandtherapy sheet enhance thickness plane ther havebeenreviewedbyparketal 166 mfnpswhichhaveacom mal conductivity sandwich panel lightweight spacecraft binationofmagneticandfluorescentpropertiesareofgreatinter 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 medicalnanodevices corretal 167 havereviewedrecentpubli optimized ratherthantakingthetraditionalapproachoftreating 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 eronetal 161 haveusedfiniteelementmodelstostudyamulti v nanometer sized particle 1000 time greater functional approach integrated multi layered thana vforamicron sizedparticle thelargea vratiosandresult sandwichisusedtoreplaceatraditionalroofpanelwithitssepa ing large pore volume porous hollow nanostructures make ratecomponents vaidyaetal 162 developedamultifunctional particularly attractive multifunctional delivery drug sandwichstructureinwhichthewovene glassfacesheetsarecon andbiomolecules recentpublicationsonthesynthesisandappli nected vertical woven e glass pile foam core cationsofhollowmicro nanostructureshavebeenreviewedbylou constructionenhances theimpactresistance sound vibration et al 168 biomedical application hollow nanostruc dampingandaccommodateswiresorsensors sandwichstructures tureshavebeenreviewedbyanandhyeon 169 oftenconsistofcompositefacesheetsandfoamcores andthereis anumberofbiomedicalapplicationsformultifunctionalmate increasedactivityintheuseofnanoparticlestoenhanceboththe rialsrequiresubstantialflexibilityinordertoaccommodatelarge 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 largerangesofdeformation biomedicalapplicationsincludeperi foaming process leading increased density reduced cell stalticpumps robotarms artificialhandsandgrippers onesuch size mechanical property foam also enhanced due class material subject considerable reinforcement effect nanoparticles lee et al 163 search ionic polymer metal composite ipmc whichr f gibson compositestructures92 2010 2793 2810 2807 fig 27 illustrationofmultifunctionalnanoparticlesystem mfnps forbiomedicalapplications reprintedfrom 164 withpermissionfromelsevier fig 28 illustrationofmultilayeredmfnps reprintedfrom 165 withkindpermissionfromspringerscience businessmedia areexcitedbyanelectricfield shahinpoorandkimhavepublished determine impact energy optical transparency mea series four review article dealing fundamental suredusingaspectrophotometer significantimprovementinim 170 manufacturing technique 171 modeling simulation pact energy achieved nano enhanced adhesive 172 industrialand biomedicalapplications 173 ofipmcs layer whiletransparencywassomewhatreducedbutacceptable electroactivepolymerswithhighdielectricconstantscanalsogen related investigation impact resistant optically transparent erate large deformation electric field reviewed compositeshavebeenreportedbyliuetal 179 rojanapitayak bar cohen 174 asanotherexample energyharvestingfromnor ornetal 180 songetal 181 andhuangetal 182 mal motion deformation human body requires theenergyconversiondevicebeveryflexible qietal 175 5 concludingremarks developed flexible energy conversion device based printing piezoelectric pzt ribbon micrometer scale width article attempt reasonably comprehensive review nanometerscalethicknessesonrubbersubstrates theuseofcar representative journal publication covering development bon nanotube flexible electronic yarn fabric use mechanicsofmultifunctionalcompositematerialsandstructures wearable biomonitoring telemedicine sensor mostofthearticleshaveappearedsince2000 andmanyinvolve ported shim et al 176 energy harvesting backpack polymercomposites nanomaterialsandnanostructures function usebysoldierswasdevelopedbygranstrometal 177 whore interest include structural property like strength stiffness placedthenylonshoulderstrapsonastandardbackpackwithflex fracturetoughness anddamping andnon structuralfunctionslike iblepvdfpiezoelectricstraps duringnormalwalkingmotions electricaland orthermalconductivity sensingandactuation en relativemotionsbetweenthesoldier sbodyandthebackpackgen ergy harvesting storage self healing capability electromagnetic erate deformation pzt strap convert interference emi shielding recyclability biodegradability deformationstoelectricalenergyforuseinpoweringsmallporta much future research multifunctional material bleelectronicdevicescarriedbythesoldier structure driven structural application like multifunctionality impact resistant material military aircraft butbyneedsinotherareaslikebiomedical thereisaneed transport vehicle helicopter fighter aircraft becoming formoreanalyticalmodelingworkinmostoftheareascoveredin increasinglyimportant andoneexampleisopticallytransparent thisreview sincemostofthepublishedresultstodatetendtobe impact resistant nanocomposite material window experimentalinnature analyticalmodelsareneedednotonlyto vehicle extremely small size small concentration help interpreting experimental result optimizing nanoreinforcements make possible improve impact energy themultifunctionalmaterialorsystemforspecificapplications absorption maintaining good transparency material investigated rai singh 178 fabricated andtestedsandwichpanelsconsistingofpmmasheetswiththin acknowledgement layer nano enhanced polymer adhesive sandwiched thepolymeradhesivelayerswereenhancedwith2wt theauthorgratefullyacknowledgesthefinancialsupportfrom 35nmsizedaluminapowder dropweightimpacttestswereused award fa9550 09 1 0506 u air force office of2808 r f gibson compositestructures92 2010 2793 2810 scientificresearch andtheencouragementofdr leslee program reinfplasticscompos 2009 doi 10 1177 0731684409344652 onlinefirst manager afosr mechanic multifunctional material september8 2009 29 vlasvelddpn berseehen pickensj nanocompositematrixforincreased andmicrosystemsprogram theauthorisverygratefulfortheelec fibrecompositestrength polymer2005 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 servicethroughthemathewson igtknowledgecenterattheuni nanotubeswithdifferentmorphologiesoncarbonfibers carbon2005 43 663 5 versityofnevada reno withoutwhichthisarticlewouldnothave 31 uddinmf sunct strengthofunidirectionalglass epoxycompositewithsilica beenpossible nanoparticle enhancedmatrix composscitechnol2008 68 7 8 1637 43 32 uddinmf sunct

improveddispersionandmechanicalpropertiesofhybrid nanocomposites composscitechnol2010 70 223 30 reference 33 liu zhang h zhang z zhang sprenger tailoring mechanical property epoxy resin various nanoparticles polym polym compos 1 baur j silverman e challenge opportunity multifunctional 2008 16 8 471 7 nanocompositestructuresforaerospaceapplications mrsbull2007 32 4 34 zhangh tangl c zhang z friedrichk sprengers fracturebehavior 328 34 insitunanoparticle filledepoxyatdifferenttemperatures polymer2008 49 2 ye l lu su z meng g functionalized composite structure new 3816 25 generationairframes areview composscitechnol2005 65 9 1436 46 35 manjunathacm taylorac kinlochaj theeffectofrubbermicro particle 3 thostensonet renz chout w advancesinthescienceandtechnologyof andsilicanano particlesonthetensilefatiguebehaviorofaglassfibreepoxy carbon nanotube composite review compos sci technol composite jmatersci2009 44 342 5 2001 61 1899 912 36 choj joshims sunct effectofinclusionsizeonmechanicalpropertiesof 4 chout w gaol thostensonet zhangz byunj h anassessmentofthe polymericcompositeswithmicroandnanoparticles composscitechnol scienceandtechnologyofcarbonnanotubecomposites composscitechnol 2006 66 1941 52 2010 70 1 1 19 37 choj sunct amoleculardynamicssimulationstudyofinclusionsizeeffect 5 breuero sundararaju bigreturnsfromsmallfibers areviewofpolymer onpolymericmatrixcomposites computmatersci2007 41 54 62 carbonnanotubecomposites polymcompos2004 25 6 630 45 38 thostensonet liwz wangdz renzf chout w carbonnanotube carbon 6 li c thostenson et chou w sensor actuator based carbon fiberhybridmultiscalecomposite japplphys2002 91 9 6034 7 nanotube composite review compos sci technol 2008 68 39 veedu vp cao li x k soldano c kar et al multifunctional 1227 49 composite using reinforced lamina carbon nanotube forest nat 7 gibsonrf ayorindeeo weny f vibrationsofcarbonnanotubesandtheir mater2006 5 457 62 composite areview composscitechnol2007 67 1 28 40 garciaej hartaj wardlebl longcarbonnanotubesgrownonthesurfaceof 8 sun l gibson rf gordaninejad f suhr j energy absorption capability fibersforhybridcomposites aiaaj2008 46 6 1405 12 nanocomposites areview composscitechnol2009 69 2392 409 41 garcia ej wardle bl hart aj joining prepreg composite interface 9 bauhofer w kovacs jz review analysis electrical percolation alignedcarbonnanotubes composparta applscimanuf2008 39 1065 70 carbon nanotube polymer composite compos sci technol 2009 69 10 42 garciaej wardlebl hartaj yamamoton fabricationandmultifunctional 1486 98 propertiesofahybridlaminatewithalignedcarbonnanotubesgrowninsitu 10 birmanv byrdlw modelingandanalysisoffunctionallygradedmaterials composscitechnol2008 68 2034 41 andstructures applmechrev2007 60 1 6 195 216 43 blancoj garciaej guzmandeviloriar wardlebl limitationsofmodei 11 montalvao maia nmm ribeiro amr review vibration based interlaminar toughening composite reinforced aligned carbon structuralhealthmonitoringwithspecialemphasisoncompositematerials nanotube jcomposmater2009 43 825 41 shockvibdigest2006 38 4 295 324 44 wick guzman de villoria r wardle bl interlaminar intralaminar 12 zou tong l steven gp vibration based model dependent damage reinforcement composite laminate aligned carbon nanotube identificationandhealthmonitoringforcompositestructures areview j composscitechnol2010 70 20 8 soundvib2000 230 2 357 78 45 gibsont putthanarats fieldingjc draina willk stoffelm conductive 13 wudy meures solomond self healingpolymericmaterials areviewof nanocomposites focusonlightningstrikeprotection procintsampetech recentdevelopments progpolymsci2008 33 5 479 522 confandexhibition fromarttoscience advancingmaterandproceng 14 parkg rosingt toddmd farrarcr hodgkissw energyharvestingfor 2007 structuralhealthmonitoringsensornetworks jinfrastructsyst2008 14 1 46 allaouia bai chenghm baijb mechanicalandelectricalpropertiesofa 64 79 mwnt epoxycomposite composscitechnol2002 62 1993 8 15 sodanoha inmandj parkg areviewofpowerharvestingfromvibration 47 qiuj zhangc wangb liangr carbonnanotubeintegratedmultifunctional usingpiezoelectricmaterials shockvibdigest2004 36 3 197 205 composite nanotechnology2007 18 275708 16 anton sr sodano ha review power harvesting using piezoelectric 48 kalaitzidou k fukushima h drzal lt multifunctional polypropylene material 2003 2006 smartmaterstruct2007 16 3 r1 21 compositesproducedbyincorporationofexfoliatedgraphitenanoplatelets 17 cook chennaultka thambin sastryam poweringmemsportabledevices carbon2007 45 1446 52 areviewofnon regenerativeandregenerativepowersupplysystemswith 49 cebeci h guzman de villoria r hart aj wardle bl multifunctional specialemphasisonpiezoelectricenergyharvestingsystems smartmater property high volume fraction aligned carbon nanotube polymer struct2008 17 4 043001 composite controlled

morphology compos sci technol 2009 69 18 ratnad karger kocsisj
recentadvancesinshapememorypolymersand 2649 56 composite areview jmatersci2008 43 1 254 69
50 sandlerjkw kirkje kinlochia shaffermsp windleah ultra lowelectrical 19 gibsonr gianarisnj luchtb
beckwithsw editor proc2008sampefall percolation threshold carbon nanotube epoxy composite polymer
techconf multifunctionalmaterials workingsmartertogether september 2003 44 5893 9 8 11 2008
memphis tn socforadvofmaterandprocesseng covinaca 51 li j pc chow w ck tang bz kim j k correlation
20 lauk chengl suz varadanvk smartcompositematerials selectedpapers percolationthreshold
dispersionstate andaspectratioofcarbonnanotubes international conference multifunctional material
advfunctmater2007 17 3207 15 structure mfms 08 hong kong 28 31 july 2008 smart mater struct 52
thostenson et ziaee chou w processing electrical property 2009 18 7 070201 carbon nanotube vinyl
ester nanocomposites compos sci technol 21 gibsonrf cheny zhaoh
improvementofvibrationdampingcapacityand 2009 69 801 4 fracture toughness composite laminate use
polymeric 53 lic thostensonet chout w effectofnanotubewavinessontheelectrical interleaf
jengmatertechnol2001 123 309 14 conductivity carbon nanotube based composite compos sci technol
22 koratkar na suhr j joshi kane r schadler l ajayan pm et al 2008 68 1445 52 characterizing energy
dissipation single walled carbon nanotube 54 shenogina n shenogin xue l keblinski p lack thermal
polycarbonatecomposites applphyslett2005 87 063102 percolationincarbonnanotubecomposites
applphyslett2005 87 133106 23 zhoux shine wangkw bakisce interfacialdampingcharacteristicsof 55
biercuk mj llaguno mc radosavljevic hyun jk johnson carbon carbonnanotube basedcomposites
composscitechnol2004 64 2425 37 nanotubecompositesforthermalmanagement applphyslett2002 80
15 24 rajoria h jalili n passive vibration damping enhancement using carbon 2767 9 nanotube epoxy
reinforced composite compos sci technol 2005 65 56 bonnetp sireuded garnierb chauveto
thermalpropertiesandpercolation 2079 93 incarbonnanotube polymercomposites applphyslett2007 91
201910 25 koratkar na wei bq ajayan pm carbon nanotube film damping 57 kim ya kamio tajiri hayashi
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
featuringcarbonnanotubefilms composscitechnol2003 63 11 1525 31 58 ganguli roy ak anderson dp
improved thermal conductivity 27 tehpl mariattim akilhm yeohck seetharamakn wagimananr etal
chemically functionalized exfoliated graphite epoxy composite carbon property epoxy resin coated silica
filler composite mater lett 2008 46 5 806 17 2007 61 2156 8 59 sihns gangulis royak qul dail
enhancementofthrough thickness 28 manjunatha cm taylor ac kinloch aj sprenger tensile fatigue
thermal conductivity adhesively bonded joint using aligned
behaviorofagfrpcompositewithrubberparticlemodifiedepoxymatrix j carbonnanotubes
composscitechnol2008 68 658 65 r f gibson compositestructures92 2010 2793 2810 2809 60
lesieutrega daviscl canacouplingcoefficientofapiezoelectricdevicebe 93 luox chungddl carbonfiber
polymermatrixcompositesascapacitors higher active material j intell mater syst struct
composscitechnol2001 61 6 885 8 1997 8 10 859 67 94 liny sodanoha
characterizationofmultifunctionalstructuralcapacitors 61 giurgiutiu v zagrai characterization piezoelectric
wafer active forembeddedenergystorage japplphys2009 106 114108 sensor jintellmatersyststruct2001
11 12 959 76 95 whitesr sottosnr geubelleph moorejs kesslermr sriramsr etal 62 muralt p polcawich rg
troiler mckinstry piezoelectric thin film autonomichealingofpolymercomposites nature2001 409 794 7
sensor actuatorsandenergyharvesting mrsbull2009 34 9 658 64 96 brownen sottosnr whitesr
fracturetestingofaself healingpolymer 63 tadigadapa mateti k piezolectric mem sensor state art
composite expmech2002 42 372 9 perspective measscitechnol2009 20 092001 97 caruso mm blaiszik
bj white sr sottos nr moore j full recovery 64 hagood nw bent aa development piezoelectric fiber
composite fracturetoughnessusinganontoxicsolvent basedself healingsystem adv structuralactuation
proc34thaiaastructures structuraldynamicsand functmater2008 18 13 1898 904 materconference
aiaapaperno 93 1717 lajolla ca 1993 98 brownen whitesr sottosnr
retardationandrepairoffatiguecracksina 65 bentaa hagoodnw rogersjp
anisotropicactuationwithpiezoelectricfiber microcapsule toughened epoxy composite part manual
infiltration composite jintellmatersyststruct1995 6 338 49 composscitechnol2005 65 2466 73 66
fernandez jf dogan zhang qm tressler jf newnham hollow 99 brownen whitesr sottosnr

retardationandrepairoffatiguecracksina piezoelectriccomposites sensactuators a1996 51 183 92 microcapsule toughened epoxy composite part ii situ self healing 67 breid cannonbj piezoceramichollowfiberactivecomposites compossci composscitechnol2005 65 2474 80 technol2004 64 245 61 100 brownen whitesr sottosnr fatiguecrackpropagationinmicrocapsule 68 liny sodanoha conceptandmodelofapiezoelectricstructuralfiberfor toughenedepoxy jmatersci2006 41 19 6266 73 multifunctionalcomposites composscitechnol2008 68 1911 8 101 patelaj sottosnr wetzeled whitesr autonomichealingoflow velocity 69 liny sodanoha fabricationandelectromechanicalcharacterizationofa impact damage fiber reinforced composite compos part appl sci piezoelectricstructuralfiberformultifunctionalcomposites advfunctmater manuf2010 41 3 360 8 2009 19 592 8 102 cho sh white sr braun pv self healing polymer coating adv mater 70 fuchs shang q elkins j gordaninejad f evrensel c development 2009 21 6 645 9 characterization magnetorheological elastomer j appl polym sci 103 tooheyks sottosnr lewisja moorejs whitesr self healingmaterials 2007 105 2497 508 withmicrovascularnetworks natmater2007 6 581 5 71 linm changf k themanufactureofcompositestructureswithabuilt 104 kirkjg naiks moosbruggerjc morrisondj volkovd sokolovi self healing networkofpiezoceramics composscitechnol2002 62 919 39 epoxycompositesbasedontheuseofnanoporoussilicacapsules intjfract 72 qingxp beard kumara ooitk changf k built insensornetworkfor 2009 159 1 101 2 structuralhealthmonitoringofcompositestructure jintellmatersyststruct 105 privman v dementsov sokolov modeling self healing polymer 2007 18 1 39 49 composite reinforced nanoporous glass fiber j comput theor 73 wuz qingxp changf k damagedetectionforcompositelaminateplates nanosci2007 4 1 190 3 withadistributedhybridpzt fbgsensornetwork jintellmatersyststruct 106 williamsg traskr bondi aself healingcarbonfibrereinforcedpolymerfor 2009 20 1069 77 aerospaceapplications composparta applscimanuf2007 38 6 1525 32 74 suz wangx chenz yel wangd abuilt inactivesensornetworkfor 107 yint rongmz zhangmq zhaojq durabilityofself healingwovenglass health monitoring composite structure smart mater struct 2006 15 fabric epoxycomposites smartmaterstruct2009 18 7 074001 1939 49 108 balazsac modelingself healingmaterials matertoday2007 10 9 18 23 75 suz wangx chenz yel damageassessmentofmulti layeredcomposite 109 barberoej brecof lonettip continuumdamage healingmechanicswith structure using embedded active sensor network key eng mater applicationtoself healing intjdamagemech2005 14 1 51 81 2007 334 335 461 4 110 maitis shankarc geubelleph kiefferj continuumandmolecularlevel 76 watkins se akhavan f dua r chandrashekhara k wunsch dc impact modelingoffatiguecrackretardationinself healingpolymers jengmater induceddamagecharacterizationofcompositeplatesusingneuralnetworks technol2006 128 4 595 602 smartmaterstruct2007 16 515 24 111 geubelle ph maiti cohesive modeling fatigue crack retardation 77 haywoodj coverleypt staszewskiwj wordenk anautomatedimpact polymer crackclosureeffect engfractmech2006 73 1 22 41 monitorforacompositepanelemployingsmartsensortechnology smart 112 parkjs kimhs hahnht healingbehaviorofamatrixcrackonacarbon materstruct2005 14 265 71 fiber mendomercomposite composscitechnol2009 69 7 8 1082 7 78 yu l cheng l yam lh yan yj jiang j online damage detection 113 chung ddl material electromagnetic interference shielding j mater laminated composite shell partially filled fluid compos struct perform2000 9 3 350 4 2007 80 334 42 114 geetha kumar kks rao crk vijayan trivedi dc emi shielding 79 srivastavaa agarwala chakrabortyd duttaa controlofsmartlaminated methodsandmaterials areview japplpolymsci2009 112 4 2073 86 frp structure using artificial neural network j reinf plast compos 115 wang jing x intrinsically conducting polymer electromagnetic 2005 24 13 1353 64 interferenceshielding polymadvtechnol2005 16 4 344 51 80 lohkj kimj lynchjp kamnws kotovn multifunctionallayer layer 116 jiaqm lijb wanglf zhujw zhengm electricallyconductiveepoxyresin carbonnanotube polyelectrolytethinfilmsforstrainandcorrosionsensing composite containing polyaniline different morphology mater sci smartmaterstruct2007 16 429 38 enga2007 448 356 60 81 loh kj lynch jp kotov n passive wireless sensing using swmt based 117 huangy lin may duf lif hex etal theinfluenceofsingle walled multifunctional thin film patch int j appl electromag mech 2008 28 carbon nanotube structure electromagnetic interference shielding 887 94 efficiencyofitsepoxycomposites carbon2007 45 1614 21 82 olekm ostranderj jurgas mohwaldh kotovn kempak etal layer 118 al saleh mh sundararaj u electromagnetic interference shielding layerassembledcompositesfrommultiwallcarbonnanotubeswithdifferent mechanismsofcnt polymercomposites carbon2009 47 1738 46 morphology nanolett2004 4 10 1889 95 119 yangy guptamc dudleykl lawrencerw electromagneticinterference 83 shim b starkovich j kotov n multilayer composite vapor grown shieldingcharacteristicsofcarbonnanofiber polymercomposites jnanosci carbonnano fiber composscitechnol2006 66 1174 81 nanotechnol2007 7 2 549 54 84 sodano ha inman dj park g generation storage electricity 120 al saleh mh sundararaj u review vapor grown carbon nanofiber powerharvestingdevices jintellmatersyststruct2005 16 1 67 75 polymerconductivecomposites carbon2009 47 1 2 22 85 pereirat guoz niehs ariasj hahnht embeddingthin filmlithiumenergy 121 henshawjm hanw owensad overviewofrecyclingissuesforcomposite cellsinstructuralcomposites composscitechnol2008 68 1935 41 material jthermoplastcomposmater1996 9 1 4 20 86 pereira guo z nieh aria j hahn ht energy storage structural 122 pickering sj recycling technology thermoset composite material composite areview jcomposmater2009 43 5 549 60 currentstatus composparta applscimanuf2006 37 8 1206 15 87 kim h kang j park j hahn ht jung hc joung jw inkjet printed 123 ramakrishnas tanwk teohsh laimo recyclingofcarbonfiber peek electronics multifunctional composite structure compos sci technol composite keyengmater1998 137 1 8 2009 69 7 8 1256 64 124 vaidya uk chawla kk processing fibre reinforced thermoplastic 88 liu p sherman e jacobsen design fabrication multifunctional composite intmaterrev2008 53 4 185 218 structuralbatteries jpowersources2009 189 1 646 50 125 derosa r telfeyan e mayes j current state recycling sheet molding 89 snyderjf carterrh wetzeled electrochemicalandmechanicalbehaviorin compound related material j thermoplast compos mater mechanically robust solid polymer electrolyte use multifunctional 2005 18 3 219 40 structuralbatteries chemmater2007 19 15 3793 801 126 tall karlsson albertsson ch improvement property 90 snyder jf wong el hubbard cw evaluation commercially available mechanically recycled thermoplastic polym polym compos 1998 6 5 carbonfibers fabricsandpapersforpotentialuseinmultifunctionalenergy 261 7 storageapplications jelectrochemsoc2009 156 3 a215 24 127 bystrzejewski piotrowska g golimowski j urban p nanoparticles 91 brien dj baechle dm wetzel ed multifunctional structural composite potential toxicity waste environmental management waste manage capacitorsforusarmyapplications procintsampetechconf 38thfall 2009 29 9 2587 95 techconf globaladvmaterproceng 2006 128 nabi saheb jog jp natural fiber composite review adv polymer 92 baechle dm brien dj wetzel ed design processing structural technol1999 18 4 351 63 compositecapacitors procintsampesymposiumandexhibition mandp 129 bogoeva gacevag avellam malinconicom grozdanova gentileg errico fromcoasttocoastandaroundtheworld 2007 naturalfibereco composite polymercompos2007 28 1 98 107 2810 r f gibson compositestructures92 2010 2793 2810 130 mishra mohanty ak drzal lt misra hinrichsen g review 155 yao l wang x xu f zhao jiang qiu fabrication impact pineappleleaffibers sisalfibersandtheirbiocomposites macromolmater performance three dimensionally integrated microstrip antenna eng2004 289 11 955 74 microstripandcoaxialfeeding smartmaterstruct2009 18 095034 131 yan l mai w ye l sisal fibre composite review recent 156 matsuzakir melnykowyczm todorokia antenna sensormultifunctional development composscitechnol2000 60 11 2037 55 composite wireless detection damage compos sci technol 132 eichhornsj baillieca zafeiropoulosn mwaikamboly ansellmp dufresne 2009 69 2507 13 etal currentinternationalresearchintocellulosicfibresandcomposites j 157 wirtz r zhao jiang thermal mechanical characterization matersci2001 36 9 2107 3131 multifunctionalthermalenergystoragestructure ieeetranscomponpackag 133 cheung h ho p lau k cardona f hui natural fibre reinforced technol2009 32 1 53 62 compositesforbioengineeringandenvironmentalengineeringapplications 158 queheillaltdt carbajalg petersongp wadleyhng amultifunctionalheat compospartb eng2009 40 7 655 63 pipesandwichpanelstructure intjheatmasstransfer2008 51 1 2 312 26 134 yul deank lil polymerblendsandcompositesfromrenewableresources 159 ozakit takeyah kumem sekinek multifunctionalcompositestructures progpolymsci oxford 2006 31 6 576 602 forspacesatellites sampej2008 44 2 6 11 135 raquez j deleglise lacrampe f krawczak p thermosetting 160 silverman e multifunctional carbon foam development spacecraft bio material derived renewable resource critical review prog application sampej2005 41 3 19 27 polymersci oxford 2010 35 4 487 509 161 cameron cj wennhage p goransson p rahmqvist structural acoustic 136 gu j g gu j method currently used testing microbiological designofamultifunctionalsandwichpanelinanautomotivecontext jsand degradationanddeteriorationofawiderangeofpolymericmaterialswith structmater 2010 publishedonlinefirstjanuary28 2010 variousdegreeofdegradability areview jpolymenviron2005 13 1 65

74 162 vaidya vaidya uk uddin n impact response three dimensional 137 kumarr liud zhangl advancesinproteinousbiomaterials jbiobased multifunctionalsandwichcomposite materscieng2008 472 1 2 52 8 materbioenergy2008 2 1 1 24 163 leejl zengc caox hanx shenj xug polymernanocompositefoams 138 pandeyjk pratheepkumara misram mohantyak drzallt singhr recent composscitechnol2005 65 15 16 2344 63 advance biodegradable nanocomposites j nanosci nanotechnol 164 suhwh suhy h stuckygd multifunctionalnanosystemsattheinterfaceof 2005 5 4 497 526 physicalandlifesciences nanotoday2009 4 1 27 36 139 ray s bousmina biodegradable polymer layered silicate 165 haglund e seale goldsmith mm leary jf design multifunctional nanocomposites ingreeningthe21stcenturymaterialsworld progmater nanomedicaldevices annalsbiomedeng2009 37 10 2048 63 sci2005 50 8 962 1079 166 park k lee kang e kim k choi k kwon ic new generation 140 takemurak effectofwaterabsorptiononmechanicalpropertiesofhemp multifunctional nanoparticles cancer imaging therapy adv funct fiberreinforcedcomposite keyengmater2010 417 418 161 4 mater2009 19 10 1553 66 141 georgej klompenetj peijst thermaldegradationofgreenandupgraded 167 corrsa rakovichyp gun koyk multifunctionalmagnetic fluorescentnano flaxfibres advcomposlett2001 10 2 81 8 compositesforbiomedicalapplications nanoscalereslett2008 3 3 87 104 142 stamboulis baillie ca peijs effect environmental condition 168 lou xw archer la yang z hollow micro nanostructures synthesis mechanicalandphysicalpropertiesofflaxfibers composparta applsci application advmater2008 20 3987 4019 manuf2001 32 8 1105 15 169 k hyeon synthesis biomedical application hollow 143 thillc etchesj bondi potterk weaverp morphingskins aeronauticalj nanostructures nanotoday2009 4 4 359 73 2008 112 1129 117 39 170 shahinpoor kim k ionic polymer metal composite fundamental 144 wildschek havar plotner k composite electric morphing smartmaterstruct2001 10 1 15 trailingedgeforflightcontrolofablendedwingbodyairliner procinstmech 171 kimk shahinpoorm ionicpolymer metalcomposites ii manufacturing eng partg jaerospeng2010 224 1 1 9 technique smartmaterstruct2003 12 65 7 145 hartldj lagoudasdc calkinsft mabejh useofani60tishapememory 172 shahinpoorm kimk ionicpolymer metalcomposites iii modelingand alloy active jet engine chevron application thermomechanical simulation biomimetric sensor actuator transducer artificial characterization smartmaterstruct2010 19 1 015020 muscle smartmaterstruct2004 13 1362 88 146 hartldj mooneyjt lagoudasdc calkinsft mabejh useofani60tishape 173 shahinpoorm kimk ionicpolymer metalcomposites iv industrialand memoryalloyforactivejetenginechevronapplication ii experimentally medicalapplications smartmaterstruct2005 14 197 214 validatednumericalanalysis smartmaterstruct2010 19 1 015021 174 bar cohen electroactive polymer artificial muscle review j 147 mudupuv trabiamb yimw weinachtp designandvalidationofafuzzy spacecraftrockets2002 39 822 7 logic controller smart projectile fin piezoelectric macro fiber 175 qiy jafferisnt lyonsjrk leecm ahmadh mcalpinemc piezoelectric compositebimorphactuator smartmaterstruct2008 17 3 ribbon printed onto rubber flexible energy conversion nano lett 148 thomasjp qidwaima mechanicaldesignandperformanceofcomposite 2010 10 524 8 multifunctionalmaterials actamater2004 52 2155 64 176 shim b chen w doty c xu c kotov na smart electronic yarn 149 thomas jp qidwai design application multifunctional wearablefabricsforhumanbiomonitoringmadebycarbonnanotubecoating structure batterymaterialsystems jom2005 57 3 18 24 withpolyelectrolytes nanolett2008 8 12 4151 7 150 tussj lockyera altk uldrichf kinslowr kudvaj etal conformalload 177 granstromj feenstraj sodanoha farinholtk energyharvestingfroma bearing antenna structure proc aiaa asme asce ahs asc structure backpack instrumented piezoelectric shoulder strap smart mater structuraldynmaterconf vol 2 1996 p 836 43 struct2007 16 5 1810 20 151 lockyeraj altk kinslowrw kanh p kudvajn tussj etal development 178 rai kn singh impact resistance behavior polymer nanocomposite ofastructurallyintegratedconformalload bearingmultifunctionantenna transparentpanels jcomposmater2009 43 2 139 51 overviewoftheairforcesmartskin structurestechnologydemonstration 179 liuy hedinne fongh polycarbonate poly methylmethacrylate nanofiber program procspiesmartstructmaterconf1996 2722 55 64 compositeswithimprovedimpactstrength japplmater2008 40 3 33 42 152 berdenmj mccarvilleda structurallyintegratedx bandantennalargescale 180 rojanapitayakornp matherpt goldbergaj weissra opticallytransparent componentwingtest procintsampesympexhib mandp fromcoast self reinforced poly ethylene terephthalate composite molecular tocoastandaroundtheworld 2007 p 52 orientationandmechanicalproperties polymer2005 46 3 761 73 153 lockyer aj alt kh kudva jn tuss j air vehicle integration issue 181 songj kimj w suhk poly

methylmethacrylate tougheningwith considerationsforclassuccessfulimplementation procspiesmartstruct refractiveindex controlledcore shellcompositeparticles japplpolymsci materconf2001 4332 48 59 1999 71 10 1607 14 154 yao l qiu design fabrication microstrip antenna integrated 182 huang j yang b huang shen j core shell nanoparticles reinforced three dimensional orthogonal woven composite compos sci technol polystyrenewithnoeffectonitstransparency intjpolymmater1997 35 1 2009 69 1004 8 4 13 9

Top Keywords

composite: 0.42865846467149404
multifunctional: 0.21012669836837944
polymer: 0.21012669836837944
material: 0.1891140285315415
carbon: 0.18070896059680633
al: 0.17650642662943875
fig: 0.17650642662943875
structure: 0.17650642662943875
et: 0.16389882472733597
fiber: 0.12607601902102766
nanotube: 0.11767095108629248
self: 0.10926588315155732
structural: 0.10926588315155732
2010: 0.10086081521682214
epoxy: 0.10086081521682214
healing: 0.08825321331471937
reprintedfrom: 0.08825321331471937
review: 0.08825321331471937
gibson: 0.08405067934735178
2793: 0.07984814537998419
2810: 0.07984814537998419
energy: 0.07984814537998419
piezoelectric: 0.07984814537998419
compositestructures92: 0.0756456114126166
conductivity: 0.0756456114126166
sensor: 0.07144307744524901
18: 0.06724054347788143
compos: 0.06724054347788143
mechanical: 0.06724054347788143
particle: 0.06724054347788143
recent: 0.06724054347788143
thermal: 0.06724054347788143
10: 0.06303800951051383
application: 0.06303800951051383
function: 0.06303800951051383
matrix: 0.06303800951051383
property: 0.06303800951051383
withpermissionfromelsevier: 0.06303800951051383
13: 0.05883547554314624
14: 0.05883547554314624
2009: 0.05883547554314624
based: 0.05883547554314624
electrical: 0.05883547554314624
example: 0.05883547554314624

nanocomposites: 0.05883547554314624
use: 0.05883547554314624
sci: 0.05463294157577866
storage: 0.05463294157577866
16: 0.05043040760841107
19: 0.05043040760841107
65: 0.05043040760841107
69: 0.05043040760841107
article: 0.05043040760841107
development: 0.05043040760841107
impact: 0.05043040760841107
reinforced: 0.05043040760841107
15: 0.04622787364104348
41: 0.04622787364104348
68: 0.04622787364104348
etal: 0.04622787364104348
non: 0.04622787364104348
process: 0.04622787364104348
shielding: 0.04622787364104348
11: 0.04202533967367589
20: 0.04202533967367589
2008: 0.04202533967367589
64: 0.04202533967367589
design: 0.04202533967367589
mater: 0.04202533967367589
nano: 0.04202533967367589
nanoparticles: 0.04202533967367589
research: 0.04202533967367589
reviewed: 0.04202533967367589
size: 0.04202533967367589
strength: 0.04202533967367589
technol: 0.04202533967367589
using: 0.04202533967367589
12: 0.0378228057063083
17: 0.0378228057063083
24: 0.0378228057063083
32: 0.0378228057063083
43: 0.0378228057063083
actuator: 0.0378228057063083
areview: 0.0378228057063083
cid: 0.0378228057063083
damping: 0.0378228057063083
emi: 0.0378228057063083
fracture: 0.0378228057063083
layer: 0.0378228057063083
publication: 0.0378228057063083
reinforcement: 0.0378228057063083
related: 0.0378228057063083
time: 0.0378228057063083
2007: 0.033620271738940714
21: 0.033620271738940714
28: 0.033620271738940714
46: 0.033620271738940714

51: 0.033620271738940714
52: 0.033620271738940714
actuation: 0.033620271738940714
battery: 0.033620271738940714
cnt: 0.033620271738940714
crack: 0.033620271738940714
damage: 0.033620271738940714
film: 0.033620271738940714
forexample: 0.033620271738940714
glass: 0.033620271738940714
improvement: 0.033620271738940714
load: 0.033620271738940714
network: 0.033620271738940714
smart: 0.033620271738940714
22: 0.029417737771157312
39: 0.029417737771157312
44: 0.029417737771157312
49: 0.029417737771157312
62: 0.029417737771157312
63: 0.029417737771157312
67: 0.029417737771157312
70: 0.029417737771157312
73: 0.029417737771157312
active: 0.029417737771157312
approach: 0.029417737771157312
conducting: 0.029417737771157312
electromagnetic: 0.029417737771157312
fabric: 0.029417737771157312
foam: 0.029417737771157312
harvesting: 0.029417737771157312
micron: 0.029417737771157312
modeling: 0.029417737771157312
modulus: 0.029417737771157312
pani: 0.029417737771157312
percolation: 0.029417737771157312
possible: 0.029417737771157312
ratio: 0.029417737771157312
resin: 0.029417737771157312
several: 0.029417737771157312
sottosnr: 0.029417737771157312
toughness: 0.029417737771157312
vehicle: 0.029417737771157312
whitesr: 0.029417737771157312
25: 0.025215203804205534
27: 0.025215203804205534
60: 0.025215203804205534
61: 0.025215203804205534
87: 0.025215203804205534
aircraft: 0.025215203804205534
antenna: 0.025215203804205534
artificial: 0.025215203804205534
conventional: 0.025215203804205534
due: 0.025215203804205534

enhanced: 0.025215203804205534
high: 0.025215203804205534
however: 0.025215203804205534
improved: 0.025215203804205534
mode: 0.025215203804205534
much: 0.025215203804205534
new: 0.025215203804205534
performance: 0.025215203804205534
sensing: 0.025215203804205534
strain: 0.025215203804205534
system: 0.025215203804205534
tensile: 0.025215203804205534
used: 0.025215203804205534
vibration: 0.025215203804205534
zhang: 0.025215203804205534
149: 0.021012669836837944
2005: 0.021012669836837944
2006: 0.021012669836837944
26: 0.021012669836837944
30: 0.021012669836837944
31: 0.021012669836837944
36: 0.021012669836837944
37: 0.021012669836837944
38: 0.021012669836837944
40: 0.021012669836837944
45: 0.021012669836837944
54: 0.021012669836837944
55: 0.021012669836837944
66: 0.021012669836837944
71: 0.021012669836837944
80: 0.021012669836837944
81: 0.021012669836837944
88: 0.021012669836837944
91: 0.021012669836837944
95: 0.021012669836837944
air: 0.021012669836837944
aligned: 0.021012669836837944
asshowninfig: 0.021012669836837944
bearing: 0.021012669836837944
capacitor: 0.021012669836837944
coating: 0.021012669836837944
composscitechnol2008: 0.021012669836837944
concentration: 0.021012669836837944
conductive: 0.021012669836837944
deformation: 0.021012669836837944
developed: 0.021012669836837944
effect: 0.021012669836837944
electromagneticinterference: 0.021012669836837944
electronic: 0.021012669836837944
fatigue: 0.021012669836837944
hollow: 0.021012669836837944
important: 0.021012669836837944
increased: 0.021012669836837944

integrated: 0.021012669836837944
interference: 0.021012669836837944
interlaminar: 0.021012669836837944
ion: 0.021012669836837944
kim: 0.021012669836837944
laminate: 0.021012669836837944
li: 0.021012669836837944
loading: 0.021012669836837944
mal: 0.021012669836837944
may: 0.021012669836837944
nanostructures: 0.021012669836837944
polym: 0.021012669836837944
processing: 0.021012669836837944
pzt: 0.021012669836837944
recycling: 0.021012669836837944
reported: 0.021012669836837944
scale: 0.021012669836837944
significant: 0.021012669836837944
silica: 0.021012669836837944
simultaneous: 0.021012669836837944
small: 0.021012669836837944
sodanoha: 0.021012669836837944
thostensonet: 0.021012669836837944
type: 0.021012669836837944
volume: 0.021012669836837944
walled: 0.021012669836837944
weight: 0.021012669836837944
112: 0.016810135869470357
148: 0.016810135869470357
164: 0.016810135869470357
23: 0.016810135869470357
2795: 0.016810135869470357
29: 0.016810135869470357
33: 0.016810135869470357
34: 0.016810135869470357
35: 0.016810135869470357
42: 0.016810135869470357
50: 0.016810135869470357
53: 0.016810135869470357
59: 0.016810135869470357
74: 0.016810135869470357
78: 0.016810135869470357
93: 0.016810135869470357
98: 0.016810135869470357
achieved: 0.016810135869470357
addition: 0.016810135869470357
adv: 0.016810135869470357
advance: 0.016810135869470357
aj: 0.016810135869470357
also: 0.016810135869470357
area: 0.016810135869470357
aspect: 0.016810135869470357
biomedical: 0.016810135869470357

brownen: 0.016810135869470357
change: 0.016810135869470357
characterization: 0.016810135869470357
chout: 0.016810135869470357
cnts: 0.016810135869470357
com: 0.016810135869470357
composparta: 0.016810135869470357
compossscitechnol2005: 0.016810135869470357
conference: 0.016810135869470357
corresponding: 0.016810135869470357
described: 0.016810135869470357
detection: 0.016810135869470357
different: 0.016810135869470357
effective: 0.016810135869470357
endurance: 0.016810135869470357
energyharvesting: 0.016810135869470357
engineering: 0.016810135869470357
flexible: 0.016810135869470357
flight: 0.016810135869470357
gel: 0.016810135869470357
grown: 0.016810135869470357
gu: 0.016810135869470357
ii: 0.016810135869470357
increase: 0.016810135869470357
increasing: 0.016810135869470357
ing: 0.016810135869470357
interface: 0.016810135869470357
investigated: 0.016810135869470357
issue: 0.016810135869470357
jf: 0.016810135869470357
like: 0.016810135869470357
liu: 0.016810135869470357
manufacturing: 0.016810135869470357
mechanic: 0.016810135869470357
method: 0.016810135869470357
mfnps: 0.016810135869470357
microcapsules: 0.016810135869470357
morphology: 0.016810135869470357
multi: 0.016810135869470357
multiple: 0.016810135869470357
nanocomposite: 0.016810135869470357
nanofiber: 0.016810135869470357
natural: 0.016810135869470357
orthermalconductivity: 0.016810135869470357
park: 0.016810135869470357
poly: 0.016810135869470357
polymercomposites: 0.016810135869470357
polymeric: 0.016810135869470357
posites: 0.016810135869470357
potential: 0.016810135869470357
recently: 0.016810135869470357
reprinted: 0.016810135869470357
se: 0.016810135869470357

sensingandactuation: 0.016810135869470357
since: 0.016810135869470357
sol: 0.016810135869470357
state: 0.016810135869470357
struct: 0.016810135869470357
subject: 0.016810135869470357
sunct: 0.016810135869470357
temperature: 0.016810135869470357
ther: 0.016810135869470357
thickness: 0.016810135869470357
thin: 0.016810135869470357
three: 0.016810135869470357
threshold: 0.016810135869470357
tions: 0.016810135869470357
vaidya: 0.016810135869470357
various: 0.016810135869470357
wardle: 0.016810135869470357
web: 0.016810135869470357
well: 0.016810135869470357
woven: 0.016810135869470357
101: 0.012607601902102767
104: 0.012607601902102767
105: 0.012607601902102767
106: 0.012607601902102767
107: 0.012607601902102767
116: 0.012607601902102767
117: 0.012607601902102767
123: 0.012607601902102767
128: 0.012607601902102767
137: 0.012607601902102767
139: 0.012607601902102767
156: 0.012607601902102767
159: 0.012607601902102767
161: 0.012607601902102767
165: 0.012607601902102767
2797: 0.012607601902102767
2805: 0.012607601902102767
2807: 0.012607601902102767
47: 0.012607601902102767
56: 0.012607601902102767
57: 0.012607601902102767
75: 0.012607601902102767
76: 0.012607601902102767
77: 0.012607601902102767
79: 0.012607601902102767
86: 0.012607601902102767
89: 0.012607601902102767
90: 0.012607601902102767
92: 0.012607601902102767
94: 0.012607601902102767
96: 0.012607601902102767
97: 0.012607601902102767
absorption: 0.012607601902102767

achieve: 0.012607601902102767
acoustic: 0.012607601902102767
among: 0.012607601902102767
amount: 0.012607601902102767
appeared: 0.012607601902102767
appl: 0.012607601902102767
behavior: 0.012607601902102767
bio: 0.012607601902102767
biodegradable: 0.012607601902102767
bl: 0.012607601902102767
break: 0.012607601902102767
businessmedia: 0.012607601902102767
capability: 0.012607601902102767
carbonnanotube: 0.012607601902102767
case: 0.012607601902102767
changf: 0.012607601902102767
co: 0.012607601902102767
coated: 0.012607601902102767
containing: 0.012607601902102767
convert: 0.012607601902102767
core: 0.012607601902102767
critical: 0.012607601902102767
cure: 0.012607601902102767
data: 0.012607601902102767
dealing: 0.012607601902102767
density: 0.012607601902102767
discharge: 0.012607601902102767
dj: 0.012607601902102767
elastomer: 0.012607601902102767
electric: 0.012607601902102767
electricaland: 0.012607601902102767
electrolyte: 0.012607601902102767
electronics: 0.012607601902102767
embedded: 0.012607601902102767
excellent: 0.012607601902102767
experimental: 0.012607601902102767
fabricate: 0.012607601902102767
fabrication: 0.012607601902102767
fibre: 0.012607601902102767
field: 0.012607601902102767
filler: 0.012607601902102767
focus: 0.012607601902102767
found: 0.012607601902102767
fraction: 0.012607601902102767
functional: 0.012607601902102767
functionalized: 0.012607601902102767
garciaej: 0.012607601902102767
great: 0.012607601902102767
growth: 0.012607601902102767
healingcapability: 0.012607601902102767
healingmaterials: 0.012607601902102767
higher: 0.012607601902102767
huang: 0.012607601902102767

imaging: 0.012607601902102767
improve: 0.012607601902102767
improving: 0.012607601902102767
indicated: 0.012607601902102767
infig: 0.012607601902102767
interest: 0.012607601902102767
interleaf: 0.012607601902102767
ionicpolymer: 0.012607601902102767
jcomposmater2009: 0.012607601902102767
jiang: 0.012607601902102767
journal: 0.012607601902102767
jp: 0.012607601902102767
kimk: 0.012607601902102767
kotov: 0.012607601902102767
large: 0.012607601902102767
level: 0.012607601902102767
liny: 0.012607601902102767
lithium: 0.012607601902102767
low: 0.012607601902102767
maiti: 0.012607601902102767
many: 0.012607601902102767
mechanically: 0.012607601902102767
metalcomposites: 0.012607601902102767
microcapsule: 0.012607601902102767
model: 0.012607601902102767
module: 0.012607601902102767
molding: 0.012607601902102767
multifunctionalmaterials: 0.012607601902102767
multiscale: 0.012607601902102767
muscle: 0.012607601902102767
must: 0.012607601902102767
na: 0.012607601902102767
needed: 0.012607601902102767
one: 0.012607601902102767
panel: 0.012607601902102767
paper: 0.012607601902102767
part: 0.012607601902102767
passive: 0.012607601902102767
permissionfromelsevier: 0.012607601902102767
plastic: 0.012607601902102767
posite: 0.012607601902102767
printed: 0.012607601902102767
published: 0.012607601902102767
recyclabilityandbiodegradability: 0.012607601902102767
reno: 0.012607601902102767
representative: 0.012607601902102767
resistant: 0.012607601902102767
result: 0.012607601902102767
resulting: 0.012607601902102767
saleh: 0.012607601902102767
sandwich: 0.012607601902102767
search: 0.012607601902102767
section: 0.012607601902102767

shahinpoorm: 0.012607601902102767
shim: 0.012607601902102767
show: 0.012607601902102767
signal: 0.012607601902102767
silverman: 0.012607601902102767
smartmaterstruct2007: 0.012607601902102767
sodano: 0.012607601902102767
solvent: 0.012607601902102767
sr: 0.012607601902102767
stiffness: 0.012607601902102767
struc: 0.012607601902102767
structuralbatteries: 0.012607601902102767
structuralfunctions: 0.012607601902102767
structurally: 0.012607601902102767
sundararaj: 0.012607601902102767
suz: 0.012607601902102767
technique: 0.012607601902102767
test: 0.012607601902102767
testing: 0.012607601902102767
thermoplastic: 0.012607601902102767
tion: 0.012607601902102767
transition: 0.012607601902102767
transport: 0.012607601902102767
true: 0.012607601902102767
vapor: 0.012607601902102767
village: 0.012607601902102767
wardlebl: 0.012607601902102767
white: 0.012607601902102767
wireless: 0.012607601902102767
withkindpermissionfromspringerscience: 0.012607601902102767
withpermission: 0.012607601902102767
yu: 0.012607601902102767
zhao: 0.012607601902102767
þw: 0.012607601902102767
04wt: 0.008405067934735179
08: 0.008405067934735179
100: 0.008405067934735179
1000: 0.008405067934735179
1016: 0.008405067934735179
102: 0.008405067934735179
103: 0.008405067934735179
108: 0.008405067934735179
109: 0.008405067934735179
110: 0.008405067934735179
111: 0.008405067934735179
113: 0.008405067934735179
114: 0.008405067934735179
115: 0.008405067934735179
118: 0.008405067934735179
119: 0.008405067934735179
120: 0.008405067934735179
121: 0.008405067934735179
122: 0.008405067934735179

124: 0.008405067934735179
125: 0.008405067934735179
126: 0.008405067934735179
127: 0.008405067934735179
129: 0.008405067934735179
130: 0.008405067934735179
131: 0.008405067934735179
132: 0.008405067934735179
133: 0.008405067934735179
134: 0.008405067934735179
135: 0.008405067934735179
136: 0.008405067934735179
138: 0.008405067934735179
140: 0.008405067934735179
141: 0.008405067934735179
142: 0.008405067934735179
143: 0.008405067934735179
144: 0.008405067934735179
145: 0.008405067934735179
146: 0.008405067934735179
147: 0.008405067934735179
150: 0.008405067934735179
1525: 0.008405067934735179
153: 0.008405067934735179
154: 0.008405067934735179
155: 0.008405067934735179
157: 0.008405067934735179
158: 0.008405067934735179
160: 0.008405067934735179
162: 0.008405067934735179
163: 0.008405067934735179
166: 0.008405067934735179
167: 0.008405067934735179
168: 0.008405067934735179
169: 0.008405067934735179
170: 0.008405067934735179
171: 0.008405067934735179
172: 0.008405067934735179
173: 0.008405067934735179
174: 0.008405067934735179
175: 0.008405067934735179
176: 0.008405067934735179
177: 0.008405067934735179
178: 0.008405067934735179
179: 0.008405067934735179
180: 0.008405067934735179
181: 0.008405067934735179
182: 0.008405067934735179
197: 0.008405067934735179
1993: 0.008405067934735179
2003: 0.008405067934735179
2010elsevierltd: 0.008405067934735179
2799: 0.008405067934735179

2801: 0.008405067934735179
2803: 0.008405067934735179
312: 0.008405067934735179
334: 0.008405067934735179
3d: 0.008405067934735179
409: 0.008405067934735179
48: 0.008405067934735179
549: 0.008405067934735179
58: 0.008405067934735179
602: 0.008405067934735179
658: 0.008405067934735179
72: 0.008405067934735179
7wt: 0.008405067934735179
801: 0.008405067934735179
82: 0.008405067934735179
83: 0.008405067934735179
84: 0.008405067934735179
85: 0.008405067934735179
ability: 0.008405067934735179
access: 0.008405067934735179
acknowledgement: 0.008405067934735179
adhesive: 0.008405067934735179
agent: 0.008405067934735179
ajayan: 0.008405067934735179
ak: 0.008405067934735179
allrightsreserved: 0.008405067934735179
already: 0.008405067934735179
although: 0.008405067934735179
altk: 0.008405067934735179
analysis: 0.008405067934735179
analytical: 0.008405067934735179
andnon: 0.008405067934735179
andstructures: 0.008405067934735179
applied: 0.008405067934735179
applphyslett2005: 0.008405067934735179
applphyslett2007: 0.008405067934735179
art: 0.008405067934735179
assembly: 0.008405067934735179
associated: 0.008405067934735179
attempt: 0.008405067934735179
author: 0.008405067934735179
available: 0.008405067934735179
backpack: 0.008405067934735179
baechle: 0.008405067934735179
bai: 0.008405067934735179
bar: 0.008405067934735179
becoming: 0.008405067934735179
believed: 0.008405067934735179
bers: 0.008405067934735179
best: 0.008405067934735179
biercuk: 0.008405067934735179
biodegradability: 0.008405067934735179
body: 0.008405067934735179

bogoeva: 0.008405067934735179
bondi: 0.008405067934735179
brien: 0.008405067934735179
ca: 0.008405067934735179
calkinsft: 0.008405067934735179
carbon2007: 0.008405067934735179
carbon2009: 0.008405067934735179
carbonnanotubecomposites: 0.008405067934735179
carbonnanotubes: 0.008405067934735179
catalyst: 0.008405067934735179
cation: 0.008405067934735179
causing: 0.008405067934735179
cell: 0.008405067934735179
cent: 0.008405067934735179
chawla: 0.008405067934735179
chealed: 0.008405067934735179
chemical: 0.008405067934735179
chemically: 0.008405067934735179
cheng: 0.008405067934735179
chenz: 0.008405067934735179
choice: 0.008405067934735179
choj: 0.008405067934735179
chou: 0.008405067934735179
chung: 0.008405067934735179
coefficient: 0.008405067934735179
cohen: 0.008405067934735179
cohesive: 0.008405067934735179
collected: 0.008405067934735179
compared: 0.008405067934735179
component: 0.008405067934735179
compositestructuralmaterials: 0.008405067934735179
composscitechnol: 0.008405067934735179
composscitechnol2002: 0.008405067934735179
composscitechnol2009: 0.008405067934735179
composscitechnol2010: 0.008405067934735179
compressive: 0.008405067934735179
compstruct: 0.008405067934735179
concept: 0.008405067934735179
concluded: 0.008405067934735179
concludingremarks: 0.008405067934735179
condition: 0.008405067934735179
conductor: 0.008405067934735179
considerable: 0.008405067934735179
consisting: 0.008405067934735179
control: 0.008405067934735179
conversion: 0.008405067934735179
copyright: 0.008405067934735179
corrosion: 0.008405067934735179
coupling: 0.008405067934735179
cvirgin: 0.008405067934735179
cycle: 0.008405067934735179
dc: 0.008405067934735179
de: 0.008405067934735179

definition: 0.008405067934735179
demonstrated: 0.008405067934735179
dependent: 0.008405067934735179
derived: 0.008405067934735179
derosa: 0.008405067934735179
dielectric: 0.008405067934735179
dimensional: 0.008405067934735179
dispersion: 0.008405067934735179
dm: 0.008405067934735179
doi: 0.008405067934735179
dominated: 0.008405067934735179
driven: 0.008405067934735179
drug: 0.008405067934735179
drzal: 0.008405067934735179
ductivity: 0.008405067934735179
earlier: 0.008405067934735179
ed: 0.008405067934735179
effectiveness: 0.008405067934735179
efficiency: 0.008405067934735179
electrically: 0.008405067934735179
electrode: 0.008405067934735179
energydensity: 0.008405067934735179
eng: 0.008405067934735179
environmental: 0.008405067934735179
erate: 0.008405067934735179
ergy: 0.008405067934735179
exfoliated: 0.008405067934735179
extensive: 0.008405067934735179
extremely: 0.008405067934735179
face: 0.008405067934735179
feasibility: 0.008405067934735179
fi: 0.008405067934735179
filled: 0.008405067934735179
flax: 0.008405067934735179
fluorescent: 0.008405067934735179
form: 0.008405067934735179
fracturetoughness: 0.008405067934735179
frictional: 0.008405067934735179
fundamental: 0.008405067934735179
generation: 0.008405067934735179
geubelle: 0.008405067934735179
geubelleph: 0.008405067934735179
gibsonrf: 0.008405067934735179
good: 0.008405067934735179
gordaninejad: 0.008405067934735179
graphite: 0.008405067934735179
green: 0.008405067934735179
guzman: 0.008405067934735179
ha: 0.008405067934735179
hahn: 0.008405067934735179
hahnht: 0.008405067934735179
hart: 0.008405067934735179
hartaj: 0.008405067934735179

hartldj: 0.008405067934735179
healed: 0.008405067934735179
health: 0.008405067934735179
heat: 0.008405067934735179
help: 0.008405067934735179
ht: 0.008405067934735179
hybrid: 0.008405067934735179
hybridmultiscalestructuralcompositematerials: 0.008405067934735179
ichealed: 0.008405067934735179
icvirgin: 0.008405067934735179
im: 0.008405067934735179
inclusion: 0.008405067934735179
incorporate: 0.008405067934735179
industrialand: 0.008405067934735179
information: 0.008405067934735179
inkjet: 0.008405067934735179
integratedstructuralandnon: 0.008405067934735179
international: 0.008405067934735179
interpreting: 0.008405067934735179
intralaminar: 0.008405067934735179
introduction: 0.008405067934735179
investigation: 0.008405067934735179
involved: 0.008405067934735179
ionic: 0.008405067934735179
iron: 0.008405067934735179
ites: 0.008405067934735179
ity: 0.008405067934735179
jet: 0.008405067934735179
jintellmatersyststruct: 0.008405067934735179
jog: 0.008405067934735179
kang: 0.008405067934735179
key: 0.008405067934735179
kgaa: 0.008405067934735179
kimj: 0.008405067934735179
kocsis: 0.008405067934735179
koratkar: 0.008405067934735179
kotovn: 0.008405067934735179
kumar: 0.008405067934735179
lack: 0.008405067934735179
lagoudasdc: 0.008405067934735179
lamina: 0.008405067934735179
layered: 0.008405067934735179
lbl: 0.008405067934735179
lee: 0.008405067934735179
lett: 0.008405067934735179
lie: 0.008405067934735179
life: 0.008405067934735179
likely: 0.008405067934735179
linandsodano: 0.008405067934735179
literature: 0.008405067934735179
longitudinal: 0.008405067934735179
lt: 0.008405067934735179
lu: 0.008405067934735179

mabejh: 0.008405067934735179
made: 0.008405067934735179
magnetic: 0.008405067934735179
make: 0.008405067934735179
mandp: 0.008405067934735179
manjunatha: 0.008405067934735179
measured: 0.008405067934735179
mechanism: 0.008405067934735179
mem: 0.008405067934735179
memory: 0.008405067934735179
ments: 0.008405067934735179
metal: 0.008405067934735179
methylmethacrylate: 0.008405067934735179
mfms: 0.008405067934735179
mh: 0.008405067934735179
micro: 0.008405067934735179
microstrip: 0.008405067934735179
mishra: 0.008405067934735179
mm: 0.008405067934735179
modified: 0.008405067934735179
molecular: 0.008405067934735179
monitoring: 0.008405067934735179
moorejs: 0.008405067934735179
morphing: 0.008405067934735179
motion: 0.008405067934735179
multifunctionality: 0.008405067934735179
multilayer: 0.008405067934735179
multiplestructuralfunctions: 0.008405067934735179
mwnt: 0.008405067934735179
mwnts: 0.008405067934735179
nabi: 0.008405067934735179
nanograss: 0.008405067934735179
nanomaterials: 0.008405067934735179
nanoparticle: 0.008405067934735179
nanoreinforcements: 0.008405067934735179
nanotoday2009: 0.008405067934735179
nificantly: 0.008405067934735179
number: 0.008405067934735179
often: 0.008405067934735179
opportunity: 0.008405067934735179
optical: 0.008405067934735179
optimizing: 0.008405067934735179
organic: 0.008405067934735179
orthogonal: 0.008405067934735179
oxford: 0.008405067934735179
parkg: 0.008405067934735179
particularly: 0.008405067934735179
pc: 0.008405067934735179
percolationthreshold: 0.008405067934735179
phenolic: 0.008405067934735179
pickering: 0.008405067934735179
pl: 0.008405067934735179
pm: 0.008405067934735179

polymer2005: 0.008405067934735179
poor: 0.008405067934735179
power: 0.008405067934735179
pr: 0.008405067934735179
prepreg: 0.008405067934735179
program: 0.008405067934735179
provide: 0.008405067934735179
qingxp: 0.008405067934735179
qiu: 0.008405067934735179
radial: 0.008405067934735179
rai: 0.008405067934735179
range: 0.008405067934735179
ranging: 0.008405067934735179
raquez: 0.008405067934735179
receiver: 0.008405067934735179
recycled: 0.008405067934735179
reduce: 0.008405067934735179
reduced: 0.008405067934735179
reduction: 0.008405067934735179
reference: 0.008405067934735179
reproducedfrom: 0.008405067934735179
require: 0.008405067934735179
required: 0.008405067934735179
resistance: 0.008405067934735179
response: 0.008405067934735179
retardationandrepairoffatiguecracksina: 0.008405067934735179
ribbon: 0.008405067934735179
rubber: 0.008405067934735179
saheb: 0.008405067934735179
science: 0.008405067934735179
separately: 0.008405067934735179
sffiffiffiffiffiffiffiffiffiffi: 0.008405067934735179
shape: 0.008405067934735179
sheet: 0.008405067934735179
shell: 0.008405067934735179
shm: 0.008405067934735179
showed: 0.008405067934735179
shown: 0.008405067934735179
sic: 0.008405067934735179
simulation: 0.008405067934735179
simultaneously: 0.008405067934735179
singh: 0.008405067934735179
single: 0.008405067934735179
sisal: 0.008405067934735179
sized: 0.008405067934735179
skin: 0.008405067934735179
smartmaterstruct2009: 0.008405067934735179
smartmaterstruct2010: 0.008405067934735179
snyderetal: 0.008405067934735179
solid: 0.008405067934735179
sound: 0.008405067934735179
spacecraft: 0.008405067934735179
specific: 0.008405067934735179

specifically: 0.008405067934735179
sprenger: 0.008405067934735179
stanford: 0.008405067934735179
still: 0.008405067934735179
strap: 0.008405067934735179
strong: 0.008405067934735179
strongly: 0.008405067934735179
suhr: 0.008405067934735179
sun: 0.008405067934735179
surface: 0.008405067934735179
surveyed: 0.008405067934735179
synthesis: 0.008405067934735179
tall: 0.008405067934735179
techconf: 0.008405067934735179
technology: 0.008405067934735179
theempha: 0.008405067934735179
theflexural: 0.008405067934735179
therapy: 0.008405067934735179
thermoset: 0.008405067934735179
thostenson: 0.008405067934735179
thostensonetal: 0.008405067934735179
toughened: 0.008405067934735179
transduction: 0.008405067934735179
transmittedelectricfield: 0.008405067934735179
transparency: 0.008405067934735179
trical: 0.008405067934735179
tussj: 0.008405067934735179
uddin: 0.008405067934735179
uddinmf: 0.008405067934735179
uk: 0.008405067934735179
unidirectional: 0.008405067934735179
varying: 0.008405067934735179
velocity: 0.008405067934735179
villoria: 0.008405067934735179
wang: 0.008405067934735179
wangx: 0.008405067934735179
waste: 0.008405067934735179
watkins: 0.008405067934735179
wetzel: 0.008405067934735179
wetzeled: 0.008405067934735179
whereas: 0.008405067934735179
wildschek: 0.008405067934735179
window: 0.008405067934735179
wirtz: 0.008405067934735179
within: 0.008405067934735179
work: 0.008405067934735179
workingsmartertogether: 0.008405067934735179
would: 0.008405067934735179
xu: 0.008405067934735179
yan: 0.008405067934735179
yang: 0.008405067934735179
yao: 0.008405067934735179
yarn: 0.008405067934735179

ye: 0.008405067934735179
yel: 0.008405067934735179
young: 0.008405067934735179
zou: 0.008405067934735179
0025wt: 0.004202533967367589
0032794: 0.004202533967367589
015020: 0.004202533967367589
015021: 0.004202533967367589
0263: 0.004202533967367589
043001: 0.004202533967367589
05: 0.004202533967367589
0506: 0.004202533967367589
063102: 0.004202533967367589
070201: 0.004202533967367589
0731684409344652: 0.004202533967367589
074001: 0.004202533967367589
09: 0.004202533967367589
092001: 0.004202533967367589
093125: 0.004202533967367589
095034: 0.004202533967367589
1004: 0.004202533967367589
1012: 0.004202533967367589
10269: 0.004202533967367589
1065: 0.004202533967367589
1069: 0.004202533967367589
1079: 0.004202533967367589
1082: 0.004202533967367589
10showsthattheelectri: 0.004202533967367589
10wt: 0.004202533967367589
1105: 0.004202533967367589
1129: 0.004202533967367589
114108: 0.004202533967367589
1174: 0.004202533967367589
1177: 0.004202533967367589
11fromlietal: 0.004202533967367589
1206: 0.004202533967367589
1227: 0.004202533967367589
1256: 0.004202533967367589
133106: 0.004202533967367589
1353: 0.004202533967367589
1362: 0.004202533967367589
1405: 0.004202533967367589
1436: 0.004202533967367589
1445: 0.004202533967367589
1446: 0.004202533967367589
1486: 0.004202533967367589
151: 0.004202533967367589
152: 0.004202533967367589
1553: 0.004202533967367589
15showed: 0.004202533967367589
1607: 0.004202533967367589
1614: 0.004202533967367589
1637: 0.004202533967367589

1717: 0.004202533967367589
1738: 0.004202533967367589
1810: 0.004202533967367589
183: 0.004202533967367589
185: 0.004202533967367589
1889: 0.004202533967367589
189: 0.004202533967367589
1898: 0.004202533967367589
1899: 0.004202533967367589
190: 0.004202533967367589
1911: 0.004202533967367589
1935: 0.004202533967367589
1939: 0.004202533967367589
1941: 0.004202533967367589
195: 0.004202533967367589
1996: 0.004202533967367589
1997: 0.004202533967367589
1998: 0.004202533967367589
1999: 0.004202533967367589
1wt: 0.004202533967367589
2001: 0.004202533967367589
201910: 0.004202533967367589
2034: 0.004202533967367589
2037: 0.004202533967367589
2048: 0.004202533967367589
205: 0.004202533967367589
2073: 0.004202533967367589
2079: 0.004202533967367589
20wt: 0.004202533967367589
2107: 0.004202533967367589
214: 0.004202533967367589
2155: 0.004202533967367589
2156: 0.004202533967367589
216: 0.004202533967367589
218: 0.004202533967367589
219: 0.004202533967367589
223: 0.004202533967367589
224: 0.004202533967367589
230: 0.004202533967367589
2344: 0.004202533967367589
2392: 0.004202533967367589
23a: 0.004202533967367589
23b: 0.004202533967367589
23werefoundtobethebestforenergystorage: 0.004202533967367589
2425: 0.004202533967367589
245: 0.004202533967367589
2466: 0.004202533967367589
2474: 0.004202533967367589
2497: 0.004202533967367589
2507: 0.004202533967367589
254: 0.004202533967367589
2587: 0.004202533967367589
261: 0.004202533967367589

2649: 0.004202533967367589
265: 0.004202533967367589
2722: 0.004202533967367589
275708: 0.004202533967367589
2767: 0.004202533967367589
2800: 0.004202533967367589
2802: 0.004202533967367589
2804: 0.004202533967367589
2806: 0.004202533967367589
2808: 0.004202533967367589
2809: 0.004202533967367589
289: 0.004202533967367589
295: 0.004202533967367589
2c2: 0.004202533967367589
2wt: 0.004202533967367589
309: 0.004202533967367589
3131: 0.004202533967367589
3207: 0.004202533967367589
324: 0.004202533967367589
328: 0.004202533967367589
335: 0.004202533967367589
338: 0.004202533967367589
342: 0.004202533967367589
344: 0.004202533967367589
350: 0.004202533967367589
351: 0.004202533967367589
356: 0.004202533967367589
357: 0.004202533967367589
359: 0.004202533967367589
35nmsizedaluminapowder: 0.004202533967367589
360: 0.004202533967367589
372: 0.004202533967367589
3793: 0.004202533967367589
3816: 0.004202533967367589
38thfall: 0.004202533967367589
3987: 0.004202533967367589
3intensilefatiguelifeofaglass: 0.004202533967367589
4019: 0.004202533967367589
4151: 0.004202533967367589
417: 0.004202533967367589
418: 0.004202533967367589
429: 0.004202533967367589
4332: 0.004202533967367589
448: 0.004202533967367589
457: 0.004202533967367589
461: 0.004202533967367589
471: 0.004202533967367589
472: 0.004202533967367589
479: 0.004202533967367589
487: 0.004202533967367589
497: 0.004202533967367589
4fromzhaoetal: 0.004202533967367589
4lm: 0.004202533967367589

508: 0.004202533967367589
509: 0.004202533967367589
515: 0.004202533967367589
522: 0.004202533967367589
524: 0.004202533967367589
526: 0.004202533967367589
576: 0.004202533967367589
581: 0.004202533967367589
5893: 0.004202533967367589
592: 0.004202533967367589
595: 0.004202533967367589
5mmdown: 0.004202533967367589
5timesmoreeffectiveinincreasingt: 0.004202533967367589
6034: 0.004202533967367589
6266: 0.004202533967367589
630: 0.004202533967367589
645: 0.004202533967367589
646: 0.004202533967367589
655: 0.004202533967367589
663: 0.004202533967367589
6decadeswhenthecntconcentrationisincreasedbyonly2dec: 0.004202533967367589
761: 0.004202533967367589
794: 0.004202533967367589
7lm: 0.004202533967367589
806: 0.004202533967367589
822: 0.004202533967367589
8223: 0.004202533967367589
825: 0.004202533967367589
836: 0.004202533967367589
859: 0.004202533967367589
885: 0.004202533967367589
887: 0.004202533967367589
904: 0.004202533967367589
912: 0.004202533967367589
919: 0.004202533967367589
955: 0.004202533967367589
959: 0.004202533967367589
962: 0.004202533967367589
99: 0.004202533967367589
997: 0.004202533967367589
a1996: 0.004202533967367589
a215: 0.004202533967367589
aa: 0.004202533967367589
abionanoen: 0.004202533967367589
able: 0.004202533967367589
absorbedmoisturehasbeenfoundtosig: 0.004202533967367589
abuilt: 0.004202533967367589
abundant: 0.004202533967367589
ac: 0.004202533967367589
acceptable: 0.004202533967367589
accordingly: 0.004202533967367589
accordingto: 0.004202533967367589
accordingtofig: 0.004202533967367589

accu: 0.004202533967367589
achievea28: 0.004202533967367589
achievedby: 0.004202533967367589
acomprehensivereviewofpub: 0.004202533967367589
actamater2004: 0.004202533967367589
activity: 0.004202533967367589
actua: 0.004202533967367589
actuationofthefiber: 0.004202533967367589
actuatornetworkinacompositelaminate: 0.004202533967367589
actuatorsandenergyharvesting: 0.004202533967367589
actuatorsbasedoncarbonnanotubesandtheircomposites: 0.004202533967367589
add: 0.004202533967367589
added: 0.004202533967367589
adding: 0.004202533967367589
addressed: 0.004202533967367589
ade: 0.004202533967367589
adhesively: 0.004202533967367589
advancesinproteinousbiomaterials: 0.004202533967367589
advancesinthescienceandtechnologyof: 0.004202533967367589
advancingmaterandproceng: 0.004202533967367589
advantage: 0.004202533967367589
advcomposlett2001: 0.004202533967367589
advfunctmater: 0.004202533967367589
advfunctmater2007: 0.004202533967367589
advmater2002: 0.004202533967367589
advmater2008: 0.004202533967367589
aeronauticalj: 0.004202533967367589
aerospace: 0.004202533967367589
aerospaceapplications: 0.004202533967367589
affected: 0.004202533967367589
afosr: 0.004202533967367589
agarwala: 0.004202533967367589
age: 0.004202533967367589
agglomeration: 0.004202533967367589
agreement: 0.004202533967367589
ahmadh: 0.004202533967367589
ahs: 0.004202533967367589
aiaa: 0.004202533967367589
aiaaj2008: 0.004202533967367589
aiaapaperno: 0.004202533967367589
airdensity: 0.004202533967367589
ajayanpm: 0.004202533967367589
akhavan: 0.004202533967367589
akilhm: 0.004202533967367589
albertsson: 0.004202533967367589
algorithm: 0.004202533967367589
alignedcarbonnanotubes: 0.004202533967367589
alignedcntforestscanbridgeandstrengthenthisinterlaminarre: 0.004202533967367589
alignmentofthemagneticparticlesandthetemperature: 0.004202533967367589
alityinwaysthatconventionalcompositescouldnot: 0.004202533967367589
allaouia: 0.004202533967367589
alloy: 0.004202533967367589
aln: 0.004202533967367589

alongwiththeincreaseinthenumberofpublica: 0.004202533967367589
alsousedcvdto: 0.004202533967367589
alswerereviewedbywuetal: 0.004202533967367589
alt: 0.004202533967367589
althoughnotascommonaspiezoelectricwafersorthinfilms: 0.004202533967367589
althoughstructuralintegratedbatteriesare: 0.004202533967367589
althoughthemultidisciplinarynatureofthetopicwillleadtothe: 0.004202533967367589
althoughthereisalackofapercolationthresholdforther: 0.004202533967367589
althoughthisdesignrepresentsastartingpoint: 0.004202533967367589
alumi: 0.004202533967367589
alumina: 0.004202533967367589
always: 0.004202533967367589
amajorapplication: 0.004202533967367589
american: 0.004202533967367589
amoleculardynamicssimulationstudyofinclusionsizeeffect: 0.004202533967367589
amr: 0.004202533967367589
amultifunctionalheat: 0.004202533967367589
analyticalmodelsareneeded: 0.004202533967367589
analyticalmodelsareneedednotonlyto: 0.004202533967367589
analyze: 0.004202533967367589
anappliedmagneticfield: 0.004202533967367589
anaspectratioof0: 0.004202533967367589
anassessmentofthe: 0.004202533967367589
anautomatedimpact: 0.004202533967367589
andacompre: 0.004202533967367589
andanum: 0.004202533967367589
andaspectratioofcarbonnanotubes: 0.004202533967367589
andbentetal: 0.004202533967367589
andbiomolecules: 0.004202533967367589
andcheungetal: 0.004202533967367589
andchouetal: 0.004202533967367589
andcook: 0.004202533967367589
anddamping: 0.004202533967367589
andenergyharvesting: 0.004202533967367589
anderson: 0.004202533967367589
andfracturetoughnessincompositelaminatesaremadepossible: 0.004202533967367589
andhuangetal: 0.004202533967367589
andinmanycases: 0.004202533967367589
andkimetal: 0.004202533967367589
andmanyinvolve: 0.004202533967367589
andmaybedifficulttorepair: 0.004202533967367589
andmicrosystemsprogram: 0.004202533967367589
andmudupuetal: 0.004202533967367589
andnanoporous: 0.004202533967367589
andnumerouspublicationshavedealt: 0.004202533967367589
andoneexampleisopticallytransparent: 0.004202533967367589
andonlyafewpublicationshavedealtwith2804: 0.004202533967367589
andopticallytransparentimpactabsorbingstructures: 0.004202533967367589
andotherhealth: 0.004202533967367589
andotherimportant: 0.004202533967367589
andphasetransitions: 0.004202533967367589
andpolypyrrole: 0.004202533967367589
andporesorfunctionalitieswhichcanhostsmallbioac: 0.004202533967367589

andrayandbousmina: 0.004202533967367589
andre: 0.004202533967367589
andrenewableenergysourceshaveincreasedinrecentyears: 0.004202533967367589
andreviewsofrecentadvancesinsmphavebeenpublished: 0.004202533967367589
andsilicanano: 0.004202533967367589
andsince: 0.004202533967367589
andsincethediscussionofsensorsandactuatorsinthepre vi: 0.004202533967367589
andstructuresthatsimultaneouslyperform: 0.004202533967367589
andsuchamultilayeredparticleisillustrated: 0.004202533967367589
andsunetal: 0.004202533967367589
andtestedsandwichpanelsconsistingofpmmasheetswiththin: 0.004202533967367589
andthatbymeasuringthephasedelaybetweenthetrans: 0.004202533967367589
andthatpiezoelectricstruc: 0.004202533967367589
andthattheconceptcan: 0.004202533967367589
andthe: 0.004202533967367589
andthecorrespondingpiezoelectriccouplingcoefficientforconver: 0.004202533967367589
andtheencouragementofdr: 0.004202533967367589
andtheneedtoavoidduplicationinthecurrentre: 0.004202533967367589
andtheobjectiveofthispaperistoaddressthisneed: 0.004202533967367589
andthepolymermatrix: 0.004202533967367589
andthere: 0.004202533967367589
andthereis: 0.004202533967367589
andthereisaneedfordevelopmentofmoreanalyticalmod: 0.004202533967367589
andthermalstability: 0.004202533967367589
andtheshieldingeffectiveness: 0.004202533967367589
andthinfilms: 0.004202533967367589
andthis: 0.004202533967367589
andtoughness: 0.004202533967367589
andwillbedis: 0.004202533967367589
andwirelessdetectionofdamageincom: 0.004202533967367589
anexternalsourceinterfereswiththeoperationofanelectricalcir: 0.004202533967367589
anisotropicactuationwithpiezoelectricfiber: 0.004202533967367589
annalsbiomedeng2009: 0.004202533967367589
anode: 0.004202533967367589
another: 0.004202533967367589
anotherexampleofmultifunctionalstructuretechnologythatis: 0.004202533967367589
ansellmp: 0.004202533967367589
anti: 0.004202533967367589
antibodydeliveryincombinationwithdiagnosticsandthera: 0.004202533967367589
anton: 0.004202533967367589
antonandsodano: 0.004202533967367589
anumberofbiomedicalapplicationsformultifunctionalmate: 0.004202533967367589
aphotoofthisvehicleisshowninfig: 0.004202533967367589
apparent: 0.004202533967367589
applicationsandbytechnologicaladvancesincompositematerials: 0.004202533967367589
applicationtoself: 0.004202533967367589
applmechrev2007: 0.004202533967367589
applphyslett2002: 0.004202533967367589
applsci: 0.004202533967367589
applscimanuf2006: 0.004202533967367589
applscimanuf2007: 0.004202533967367589
applscimanuf2008: 0.004202533967367589
approachtohybrid: 0.004202533967367589

approachtothedevelopmentofstructuresistoaddresstheload: 0.004202533967367589
archer: 0.004202533967367589
archived: 0.004202533967367589
areasgoodorbetterthanthatofglass: 0.004202533967367589
areexcitedbyanelectricfield: 0.004202533967367589
arerelatedtothosetopics: 0.004202533967367589
areviewof: 0.004202533967367589
areviewofnon: 0.004202533967367589
areviewofpolymer: 0.004202533967367589
areviewofpowerharvestingfromvibration: 0.004202533967367589
aria: 0.004202533967367589
ariasj: 0.004202533967367589
array: 0.004202533967367589
articlehistory: 0.004202533967367589
articlescoveringdevelopmentsinbothmultiplestructuralfunctionsandinte: 0.004202533967367589
articlesonenergyharvesting: 0.004202533967367589
articlesrelatedtomultifunctionalnanoparticles: 0.004202533967367589
artificialhandsandgrippers: 0.004202533967367589
asabiologicalsystemwould: 0.004202533967367589
asanantenna: 0.004202533967367589
asanotherexample: 0.004202533967367589
asc: 0.004202533967367589
asce: 0.004202533967367589
asdiscussedinthe: 0.004202533967367589
aself: 0.004202533967367589
asiron: 0.004202533967367589
asme: 0.004202533967367589
asparticleagglomerationwasavoided: 0.004202533967367589
asreportedbyfuchsetal: 0.004202533967367589
asshownclearly: 0.004202533967367589
asshowninfigs: 0.004202533967367589
assisted: 0.004202533967367589
associetalconcernsaboutenvironmentalimpact: 0.004202533967367589
astheynaturallypossesstherequiredelectromechanical: 0.004202533967367589
aswellasforotherfunctionslikeenergy: 0.004202533967367589
aswiththehollowpiezoelectricfiberin: 0.004202533967367589
athighenergylevels: 0.004202533967367589
atrulyautonomousmultifunctionalstructurewillbecapableof: 0.004202533967367589
attachment: 0.004202533967367589
attention: 0.004202533967367589
attractive: 0.004202533967367589
automobile: 0.004202533967367589
automotive: 0.004202533967367589
autonomichealingoflow: 0.004202533967367589
autonomichealingofpolymercomposites: 0.004202533967367589
availableonline8may2010: 0.004202533967367589
avellam: 0.004202533967367589
avoid: 0.004202533967367589
award: 0.004202533967367589
ayorindeeo: 0.004202533967367589
baechleetal: 0.004202533967367589
baijb: 0.004202533967367589
baillie: 0.004202533967367589

baillieca: 0.004202533967367589
bakisce: 0.004202533967367589
balazs: 0.004202533967367589
balazsac: 0.004202533967367589
bandantennalargescale: 0.004202533967367589
barberoej: 0.004202533967367589
barberoetal: 0.004202533967367589
basedcarbonfabricsyieldedthebestbalancebetweenelectro: 0.004202533967367589
basedcomposites: 0.004202533967367589
basedinfor: 0.004202533967367589
basedinformationservice: 0.004202533967367589
basedontheuseofpztactuatorsandfiberbragggrating: 0.004202533967367589
basedself: 0.004202533967367589
basedshmofcomposite: 0.004202533967367589
baseline: 0.004202533967367589
basic: 0.004202533967367589
batio: 0.004202533967367589
batterymaterialsystems: 0.004202533967367589
batterysubsystemweight: 0.004202533967367589
bauhofer: 0.004202533967367589
bauhoferandkovacs: 0.004202533967367589
baur: 0.004202533967367589
baurandsilverman: 0.004202533967367589
beappliedtoeitheractiveorpassivesensingtomonitorthehealth: 0.004202533967367589
beard: 0.004202533967367589
bearingfunctions: 0.004202533967367589
bearingmaterialsand: 0.004202533967367589
bearingmultifunctionalcompositestructures: 0.004202533967367589
bearingmultifunctionalstructures: 0.004202533967367589
bearingmultifunctionantenna: 0.004202533967367589
bearingstructure: 0.004202533967367589
bearingstructurethathasthecapability: 0.004202533967367589
beckwithsw: 0.004202533967367589
become: 0.004202533967367589
beenbased: 0.004202533967367589
beenpossible: 0.004202533967367589
behaviorofagfrpcompositewithrubberparticlemodifiedepoxymatrix: 0.004202533967367589
behind: 0.004202533967367589
beneathanepoxycoatingtoenablecontinuousdeliveryofhealing: 0.004202533967367589
bent: 0.004202533967367589
bentaa: 0.004202533967367589
ber: 0.004202533967367589
berdenmj: 0.004202533967367589
berofrelevantreviewarticleshavealreadybeenpublishedabout: 0.004202533967367589
beropticsensorsinsteadofusingpztsforbothactuatingandsens: 0.004202533967367589
berseehen: 0.004202533967367589
betheprimaryreasonfortheimprovements: 0.004202533967367589
bigreturnsfromsmallfibers: 0.004202533967367589
bilities: 0.004202533967367589
binationofmagneticandfluorescentpropertiesareofgreatinter: 0.004202533967367589
biological: 0.004202533967367589
biomedicalapplications: 0.004202533967367589
biomedicalapplicationsincludeperi: 0.004202533967367589

biomedicalnanoparticles: 0.004202533967367589
biomimetric: 0.004202533967367589
biomonitoring: 0.004202533967367589
birmanv: 0.004202533967367589
bj: 0.004202533967367589
blaiszik: 0.004202533967367589
blancoj: 0.004202533967367589
bleelectronicdevicescarriedbythesoldier: 0.004202533967367589
blendsoficpssuchaspaniwith: 0.004202533967367589
bon: 0.004202533967367589
bond: 0.004202533967367589
bonded: 0.004202533967367589
bonnet: 0.004202533967367589
bonnetp: 0.004202533967367589
bousmina: 0.004202533967367589
bq: 0.004202533967367589
braun: 0.004202533967367589
breakarepossiblewithseveraltypesofthesehybridnanocompos: 0.004202533967367589
brecof: 0.004202533967367589
brei: 0.004202533967367589
breid: 0.004202533967367589
breuerandsundararaj: 0.004202533967367589
breuero: 0.004202533967367589
brieflyreviewedcomputationalmodelsforself: 0.004202533967367589
briefoverviewsofrepresentativereviewarticles: 0.004202533967367589
brienetal: 0.004202533967367589
broader: 0.004202533967367589
bubble: 0.004202533967367589
building: 0.004202533967367589
built: 0.004202533967367589
butbyneedsinotherareaslikebiomedical: 0.004202533967367589
butforelec: 0.004202533967367589
butgraphiteloadinglevelsgreaterthan4wt: 0.004202533967367589
butit: 0.004202533967367589
butmostanalyticalmodelsarebasedontheassumptionthat: 0.004202533967367589
buttherewasnosignifi: 0.004202533967367589
bychoetal: 0.004202533967367589
byintegratingapoly: 0.004202533967367589
bymixingsilicamicroparticlesandepoxyintherightpropor: 0.004202533967367589
bypermissionfrommacmillanpublishersltd: 0.004202533967367589
bypermissionofthesocietyfortheadvancementofmaterialandprocess: 0.004202533967367589
byratnaandkarger: 0.004202533967367589
byrd: 0.004202533967367589
byrdlw: 0.004202533967367589
byrtmandfilamentwindingprocesses: 0.004202533967367589
bystrzejewski: 0.004202533967367589
bysuetal: 0.004202533967367589
bythepotentialforsuchimprovements: 0.004202533967367589
bythomasandqidwai: 0.004202533967367589
byunj: 0.004202533967367589
bz: 0.004202533967367589
calconductivityofcnt: 0.004202533967367589
called: 0.004202533967367589

calreactivity: 0.004202533967367589
cam: 0.004202533967367589
cameron: 0.004202533967367589
canacouplingcoefficientofapiezoelectricdevicebe: 0.004202533967367589
canbeembeddedinstructuresforsensingand: 0.004202533967367589
canbetransformedtoconductingmaterials: 0.004202533967367589
cancer: 0.004202533967367589
cannon: 0.004202533967367589
cannonbj: 0.004202533967367589
canprovidearestiffness: 0.004202533967367589
cant: 0.004202533967367589
cantileverbeam: 0.004202533967367589
cantly: 0.004202533967367589
cao: 0.004202533967367589
caox: 0.004202533967367589
capable: 0.004202533967367589
capacitance: 0.004202533967367589
capacitorsforusarmyapplications: 0.004202533967367589
capsulatedhealingagentandacatalystforpolymerizingtheheal: 0.004202533967367589
car: 0.004202533967367589
carbajalg: 0.004202533967367589
carbon2005: 0.004202533967367589
carbonfiber: 0.004202533967367589
carbonfibers: 0.004202533967367589
carbonnano: 0.004202533967367589
carbonnanotubeintegratedmultifunctional: 0.004202533967367589
carbonnanotubepapersandnanofoampapersforpossibleuseas: 0.004202533967367589
carbonyl: 0.004202533967367589
cardona: 0.004202533967367589
carlosimulationsto: 0.004202533967367589
carrying: 0.004202533967367589
carterrh: 0.004202533967367589
caruso: 0.004202533967367589
carusoetal: 0.004202533967367589
catedinsection3: 0.004202533967367589
cationsofhollowmicro: 0.004202533967367589
cause: 0.004202533967367589
causethefracturetoughnesstodropoffwhilethedampingkeeps: 0.004202533967367589
ce: 0.004202533967367589
cebeci: 0.004202533967367589
ceedings: 0.004202533967367589
cellsinstructuralcomposites: 0.004202533967367589
cellulosic: 0.004202533967367589
cently: 0.004202533967367589
centreviewarticleshavediscussedvariousaspectsofemishield: 0.004202533967367589
cessing: 0.004202533967367589
ch: 0.004202533967367589
chakrabortyd: 0.004202533967367589
challenge: 0.004202533967367589
challenging: 0.004202533967367589
chandrashekhara: 0.004202533967367589
changematerial: 0.004202533967367589
characteristic: 0.004202533967367589

characterizationofmultifunctionalstructuralcapacitors: 0.004202533967367589
characterizes: 0.004202533967367589
characterizing: 0.004202533967367589
charged: 0.004202533967367589
chauveto: 0.004202533967367589
chemi: 0.004202533967367589
chemicalsociety: 0.004202533967367589
chemmater2007: 0.004202533967367589
chen: 0.004202533967367589
chenghm: 0.004202533967367589
chengl: 0.004202533967367589
chennaultetal: 0.004202533967367589
chennaultka: 0.004202533967367589
cheny: 0.004202533967367589
cheung: 0.004202533967367589
chevron: 0.004202533967367589
cho: 0.004202533967367589
choandsun: 0.004202533967367589
choi: 0.004202533967367589
chow: 0.004202533967367589
chungddl: 0.004202533967367589
ci: 0.004202533967367589
ciencyandscalingissuesrelatedtomanufacturing: 0.004202533967367589
cientofthermalexpansion: 0.004202533967367589
cinogenicity: 0.004202533967367589
circuit: 0.004202533967367589
cj: 0.004202533967367589
ck: 0.004202533967367589
clability: 0.004202533967367589
clas: 0.004202533967367589
class: 0.004202533967367589
classifyandlocatethedamageincompositestructureshavebeen: 0.004202533967367589
cles: 0.004202533967367589
clesdealingwithvarioustypesofenergyabsorptioninnanocom: 0.004202533967367589
clesorglassbeads: 0.004202533967367589
cleswasbelievedtosuppressmatrixcrackingandreducedelami: 0.004202533967367589
clo: 0.004202533967367589
closely: 0.004202533967367589
closure: 0.004202533967367589
cloth: 0.004202533967367589
cm: 0.004202533967367589
cnf: 0.004202533967367589
cntintralaminarandinterlaminarreinforcement: 0.004202533967367589
cntsareneededtoproduceacceptablethermalconductivity: 0.004202533967367589
cntsgrown: 0.004202533967367589
cntsstillleadtodisproportionateincreasesincompositethermal: 0.004202533967367589
coatingonthesicfiber: 0.004202533967367589
coatingwasemployedasacylindricalcapacitor: 0.004202533967367589
coeffi: 0.004202533967367589
colleague: 0.004202533967367589
colloidal: 0.004202533967367589
combinednon: 0.004202533967367589
combining: 0.004202533967367589

combiningstructuralandnon: 0.004202533967367589
commercially: 0.004202533967367589
communication: 0.004202533967367589
comparedstiffnessanden: 0.004202533967367589
componentwingtest: 0.004202533967367589
compositeactuatorforasmartprojectilefin: 0.004202533967367589
compositebimorphactuator: 0.004202533967367589
compositecapacitors: 0.004202533967367589
compositelaminatescontainingthesmartlayer: 0.004202533967367589
compositesandwichstructurespresentsomeinterestingpossi: 0.004202533967367589
compositesforbioengineeringandenvironmentalengineeringapplications: 0.004202533967367589
compositesforbiomedicalapplications: 0.004202533967367589
compositeshas: 0.004202533967367589
compositeshavebeenreportedbyliuetal: 0.004202533967367589
compositesiseasierthanfor: 0.004202533967367589
compositesisthattheirmechanicalpropertiesaretypicallymore: 0.004202533967367589
compositesproducedbyincorporationofexfoliatedgraphitenanoplatelets: 0.004202533967367589
compositeswithimprovedimpactstrength: 0.004202533967367589
compospartb: 0.004202533967367589
compossci: 0.004202533967367589
composscitechnol2000: 0.004202533967367589
composscitechnol2001: 0.004202533967367589
composscitechnol2003: 0.004202533967367589
composscitechnol2004: 0.004202533967367589
composscitechnol2006: 0.004202533967367589
composscitechnol2007: 0.004202533967367589
compound: 0.004202533967367589
comprehensive: 0.004202533967367589
compression: 0.004202533967367589
comput: 0.004202533967367589
computmatersci2007: 0.004202533967367589
con: 0.004202533967367589
conate: 0.004202533967367589
concen: 0.004202533967367589
concentrationofcarbonnanotubes: 0.004202533967367589
conceptandmodelofapiezoelectricstructuralfiberfor: 0.004202533967367589
conceptappliedtocompositelaminatescanpro: 0.004202533967367589
conductingfibers: 0.004202533967367589
conductingpath: 0.004202533967367589
conduction: 0.004202533967367589
conductiveandhighlystructural: 0.004202533967367589
conductivityexponent: 0.004202533967367589
conductivityofepoxyadhesivejointscanbeincreasedbyseveral: 0.004202533967367589
conductivityratiok: 0.004202533967367589
confandexhibition: 0.004202533967367589
configuration: 0.004202533967367589
conformal: 0.004202533967367589
conformalload: 0.004202533967367589
connected: 0.004202533967367589
considerationsforclassuccessfulimplementation: 0.004202533967367589
considered: 0.004202533967367589
consist: 0.004202533967367589
consistingof: 0.004202533967367589

constructionenhances: 0.004202533967367589
constructionofconventionalnon: 0.004202533967367589
constructionofnewstructuralbattery: 0.004202533967367589
contact: 0.004202533967367589
containingnanoparticles: 0.004202533967367589
content: 0.004202533967367589
contentsanddifferentpanimorphologies: 0.004202533967367589
contentslistsavailableatsciencedirect: 0.004202533967367589
contiguous: 0.004202533967367589
continuous: 0.004202533967367589
continuum: 0.004202533967367589
continuumandmolecularlevel: 0.004202533967367589
continuumdamage: 0.004202533967367589
controlled: 0.004202533967367589
controlledcore: 0.004202533967367589
controller: 0.004202533967367589
controlofsmartlaminated: 0.004202533967367589
conventionalcapacitorshavehighenergydensitybutpoorstiffness: 0.004202533967367589
convertit: 0.004202533967367589
cook: 0.004202533967367589
cooling: 0.004202533967367589
copyright2007american: 0.004202533967367589
corn: 0.004202533967367589
correlation: 0.004202533967367589
correspondingly: 0.004202533967367589
corretal: 0.004202533967367589
corrsa: 0.004202533967367589
cost: 0.004202533967367589
couldbeusedasastructuralcapacitorbytakingadvantageofthe: 0.004202533967367589
couplingcoefficient: 0.004202533967367589
couplingcoefficientforthefiberitself: 0.004202533967367589
covered: 0.004202533967367589
covering: 0.004202533967367589
coverleypt: 0.004202533967367589
coversrecentresearch: 0.004202533967367589
covinaca: 0.004202533967367589
crackclosureeffect: 0.004202533967367589
crackhealingefficiency: 0.004202533967367589
crease: 0.004202533967367589
creased: 0.004202533967367589
creasedinterestinthedevelopmentofload: 0.004202533967367589
create: 0.004202533967367589
creatingelectricallyconductingpolymercomposites: 0.004202533967367589
criticalfractureloadforvirginmodeifracturespecimen: 0.004202533967367589
crk: 0.004202533967367589
cross: 0.004202533967367589
crosstalk: 0.004202533967367589
cte: 0.004202533967367589
cuit: 0.004202533967367589
cured: 0.004202533967367589
curedandblockedthediffusionsitesonthemicrocapsules: 0.004202533967367589
current: 0.004202533967367589
currentinternationalresearchintocellulosicfibresandcomposites: 0.004202533967367589

currently: 0.004202533967367589
currentstatus: 0.004202533967367589
cussedfurtherinthenextsection: 0.004202533967367589
cvd: 0.004202533967367589
cw: 0.004202533967367589
dail: 0.004202533967367589
damageassessmentofmulti: 0.004202533967367589
damaged: 0.004202533967367589
damagedetectionforcompositelaminateplates: 0.004202533967367589
dampingandaccommodateswiresorsensors: 0.004202533967367589
dampingandstiffnesswasfoundtobe60wt: 0.004202533967367589
darpa: 0.004202533967367589
dashedlineinfig: 0.004202533967367589
dashedlinerepresentsdesigngoalfortruemultifunctionality: 0.004202533967367589
daviscl: 0.004202533967367589
db: 0.004202533967367589
ddl: 0.004202533967367589
dealt: 0.004202533967367589
deank: 0.004202533967367589
decoupling: 0.004202533967367589
decrease: 0.004202533967367589
decreasingparticle: 0.004202533967367589
decreasingtheweightis1: 0.004202533967367589
defined: 0.004202533967367589
deformationstoelectricalenergyforuseinpoweringsmallporta: 0.004202533967367589
degradation: 0.004202533967367589
degradationanddeteriorationofawiderangeofpolymericmaterialswith: 0.004202533967367589
degrade: 0.004202533967367589
degraded: 0.004202533967367589
delamination: 0.004202533967367589
deleglise: 0.004202533967367589
delivery: 0.004202533967367589
deliveryoftherapeuticdrugsforcancertreatment: 0.004202533967367589
dementsov: 0.004202533967367589
demonstratedthattheir: 0.004202533967367589
departmentofmechanicalengineering: 0.004202533967367589
deposition: 0.004202533967367589
describedthefabricationand: 0.004202533967367589
describedtheuseofashapememoryalloyforactivejet: 0.004202533967367589
designandvalidationofafuzzy: 0.004202533967367589
designandvalidationofafuzzylogiccontrollerandapiezoelectric: 0.004202533967367589
designofamultifunctionalsandwichpanelinanautomotivecontext: 0.004202533967367589
desirable: 0.004202533967367589
determine: 0.004202533967367589
determined: 0.004202533967367589
determines: 0.004202533967367589
develop: 0.004202533967367589
developedamultifunctional: 0.004202533967367589
developedpiezoelectric: 0.004202533967367589
developmenteffortsponsoredbytheusairforce: 0.004202533967367589
device: 0.004202533967367589
diameter: 0.004202533967367589
dielectricmismatch: 0.004202533967367589

dielectricnatureofthebatio: 0.004202533967367589
difficult: 0.004202533967367589
diffusion: 0.004202533967367589
dimensionally: 0.004202533967367589
dimensionalmicrovascularnetworksinthesubstrate: 0.004202533967367589
dis: 0.004202533967367589
discharged: 0.004202533967367589
discipline: 0.004202533967367589
discovery: 0.004202533967367589
discussed: 0.004202533967367589
discussedthe: 0.004202533967367589
dispersionstate: 0.004202533967367589
displacementcurvesformodeifracturetoughnesstestsofvirginandself: 0.004202533967367589
displacementcurvesindicate: 0.004202533967367589
dissipation: 0.004202533967367589
disturbance: 0.004202533967367589
doesnotsignificantlydegradethemechanicalbehaviorofthecom: 0.004202533967367589
dogan: 0.004202533967367589
domain: 0.004202533967367589
doty: 0.004202533967367589
double: 0.004202533967367589
dp: 0.004202533967367589
dragcoefficient: 0.004202533967367589
draina: 0.004202533967367589
drivenbyaerospaceapplicationsistheintegrationofanelectronic: 0.004202533967367589
dropweightimpacttestswereused: 0.004202533967367589
drzallt: 0.004202533967367589
dua: 0.004202533967367589
duced: 0.004202533967367589
ductility: 0.004202533967367589
ductive: 0.004202533967367589
dudleykl: 0.004202533967367589
duetoreducedweightandotherdesirableproperties: 0.004202533967367589
duetotheinterdisciplinarynatureofmultifunctionalmaterials: 0.004202533967367589
duf: 0.004202533967367589
dufresne: 0.004202533967367589
duplication: 0.004202533967367589
durabilityofself: 0.004202533967367589
duringnormalwalkingmotions: 0.004202533967367589
duttaa: 0.004202533967367589
dynamic: 0.004202533967367589
eachoftherelevantcategories: 0.004202533967367589
earliestreportsofpiezoelectricfibercomposites: 0.004202533967367589
easily: 0.004202533967367589
edgeforflightcontrolonablendedwingbodyairliner: 0.004202533967367589
editedthepro: 0.004202533967367589
editor: 0.004202533967367589
edu: 0.004202533967367589
effec: 0.004202533967367589
effectofcntaspectratioonpercolationthresholdforcntnanocomposites: 0.004202533967367589
effectofinclusionsizeonmechanicalpropertiesof: 0.004202533967367589
effectofnanotubewavinessontheelectrical: 0.004202533967367589
effectofwaterabsorptiononmechanicalpropertiesofhemp: 0.004202533967367589

effi: 0.004202533967367589
efficiencyfactorforbattery: 0.004202533967367589
efficiencyofitsepoxycomposites: 0.004202533967367589
efficiencywasachievedwithin10hofthefractureevent: 0.004202533967367589
eichhornetal: 0.004202533967367589
eichhornsj: 0.004202533967367589
eithermechanicallyrecyclethembygrindingthemintosmallpar: 0.004202533967367589
ej: 0.004202533967367589
el: 0.004202533967367589
elastic: 0.004202533967367589
electricalandther: 0.004202533967367589
electricalconductivityofcomposite: 0.004202533967367589
electricallyconductingmetallicmaterialshaveexcellentse: 0.004202533967367589
electricallyconductiveepoxyresin: 0.004202533967367589
electricalorthermalconductivityoffiller: 0.004202533967367589
electricalorthermalconductivityofmatrix: 0.004202533967367589
electricalproperties: 0.004202533967367589
electricaltransportisdominatedbythepercolatingcntnetwork: 0.004202533967367589
electricity: 0.004202533967367589
electricmorphingtrailing: 0.004202533967367589
electroactive: 0.004202533967367589
electroactivepolymerswithhighdielectricconstantscanalsogen: 0.004202533967367589
electrochemical: 0.004202533967367589
electrochemicalandmechanicalbehaviorin: 0.004202533967367589
electrodelayer: 0.004202533967367589
electromag: 0.004202533967367589
electromechanical: 0.004202533967367589
element: 0.004202533967367589
elevated: 0.004202533967367589
elimi: 0.004202533967367589
elimination: 0.004202533967367589
elkins: 0.004202533967367589
elsevier: 0.004202533967367589
elstocomplimenttheexperiments: 0.004202533967367589
embeddedbetweenthefacesheetsofcarbonfibercomposite: 0.004202533967367589
embeddedmicronsizedpiezoelectricfibersinanepoxymatrixto: 0.004202533967367589
embeddedthinfilm: 0.004202533967367589
embeddingthin: 0.004202533967367589
emishieldingcharacteristicsofcarbonnanotube: 0.004202533967367589
emishieldingeffectiveness: 0.004202533967367589
emphasis: 0.004202533967367589
emphasisofthisreviewisonthemoreaccessiblerefereedjournal: 0.004202533967367589
employed: 0.004202533967367589
en: 0.004202533967367589
ena: 0.004202533967367589
endo: 0.004202533967367589
endurancetime: 0.004202533967367589
energyabsorption: 0.004202533967367589
energydensityandspecificmodulusofmultifunctionalstructuralcapac: 0.004202533967367589
energydensitywaslowcomparedwiththatofaconventionallith: 0.004202533967367589
energyharvestingfor: 0.004202533967367589
energyharvestingfroma: 0.004202533967367589
energyharvestingfromnor: 0.004202533967367589

energyharvestingorstructuralhealthmonitoring: 0.004202533967367589
eng2004: 0.004202533967367589
eng2009: 0.004202533967367589
enga2007: 0.004202533967367589
engfractmech2006: 0.004202533967367589
engine: 0.004202533967367589
enginechevronapplications: 0.004202533967367589
english: 0.004202533967367589
enhance: 0.004202533967367589
enhancedmatrix: 0.004202533967367589
enhancedpolymeradhesivejointforimprovedthrough: 0.004202533967367589
enhancedpolymerfilmsub: 0.004202533967367589
enhancedthermalconductivity: 0.004202533967367589
enhancement: 0.004202533967367589
enhancementofthrough: 0.004202533967367589
enough: 0.004202533967367589
entitled: 0.004202533967367589
entlypublishedbyhagoodandbent: 0.004202533967367589
epoxycomposite: 0.004202533967367589
epoxycomposites: 0.004202533967367589
epoxycompositesbasedontheuseofnanoporoussilicacapsules: 0.004202533967367589
epoxycompositewingskin: 0.004202533967367589
epoxycompositewithsilica: 0.004202533967367589
epoxygradually: 0.004202533967367589
epoxyinterfacialstrength: 0.004202533967367589
epoxylaminaeand: 0.004202533967367589
epoxylaminatesbyafactor: 0.004202533967367589
epoxylaminatestoformenergy: 0.004202533967367589
epoxymonomerfromthe: 0.004202533967367589
epoxynanocompositesincreasesbynearly: 0.004202533967367589
er: 0.004202533967367589
ergydensityofvariousstructuralcapacitors: 0.004202533967367589
ergystorageandmechanicalbehaviorofthestructurearecharac: 0.004202533967367589
eronetal: 0.004202533967367589
errico: 0.004202533967367589
especially: 0.004202533967367589
essential: 0.004202533967367589
est: 0.004202533967367589
established: 0.004202533967367589
ester: 0.004202533967367589
etchesj: 0.004202533967367589
ethylene: 0.004202533967367589
evaluated: 0.004202533967367589
evaluation: 0.004202533967367589
evant: 0.004202533967367589
evantarticleshavebeenpublishedsince2000: 0.004202533967367589
even: 0.004202533967367589
evenforverycon: 0.004202533967367589
evidence: 0.004202533967367589
evrensel: 0.004202533967367589
exhibit: 0.004202533967367589
exhibited: 0.004202533967367589
existbetweenthecompositelaminae: 0.004202533967367589

expansion: 0.004202533967367589
experimentaldatashowinginverserelationshipbetweenelectricalcon: 0.004202533967367589
experimentalinnature: 0.004202533967367589
experimentally: 0.004202533967367589
expmech2002: 0.004202533967367589
extend: 0.004202533967367589
extendedthe: 0.004202533967367589
external: 0.004202533967367589
extract: 0.004202533967367589
eycombcoresandwichpanel: 0.004202533967367589
fa: 0.004202533967367589
fa9550: 0.004202533967367589
fabricated: 0.004202533967367589
fabricationandelectromechanicalcharacterizationofa: 0.004202533967367589
fabricationandmultifunctional: 0.004202533967367589
fabricsandpapersforpotentialuseinmultifunctionalenergy: 0.004202533967367589
factor: 0.004202533967367589
fall: 0.004202533967367589
far: 0.004202533967367589
farinholtk: 0.004202533967367589
farrarcr: 0.004202533967367589
faster: 0.004202533967367589
fatiguecrackpropagationinmicrocapsule: 0.004202533967367589
fbg: 0.004202533967367589
fbgsensornetwork: 0.004202533967367589
featuringcarbonnanotubefilms: 0.004202533967367589
feenstraj: 0.004202533967367589
ferentformulationsareinverselyrelated: 0.004202533967367589
fernandez: 0.004202533967367589
fers: 0.004202533967367589
ffrp: 0.004202533967367589
fgm: 0.004202533967367589
fiberhybridmultiscalecomposite: 0.004202533967367589
fiberreinforcedcomposite: 0.004202533967367589
fibersforhybridcomposites: 0.004202533967367589
fiberswith: 0.004202533967367589
fibrecompositestrength: 0.004202533967367589
fiedclassicallaminationtheorywhichincludedactuator: 0.004202533967367589
fieldingjc: 0.004202533967367589
fighter: 0.004202533967367589
filledepoxyatdifferenttemperatures: 0.004202533967367589
filledwithphase: 0.004202533967367589
filmlithiumenergy: 0.004202533967367589
fin: 0.004202533967367589
finite: 0.004202533967367589
finiteelementmodelofpiezoelectricstructuralfiberembeddedinapolymermatrix: 0.004202533967367589
firstgenerationdarpawaspmicroairvehiclewithpolymerlithium: 0.004202533967367589
flake: 0.004202533967367589
flaxfibres: 0.004202533967367589
flexural: 0.004202533967367589
flexuralmoduliofdifferentnanocompositesatvariousparticleloadings: 0.004202533967367589
flexuralstrengthsofdifferentnanocompositesatvariousparticleloadings: 0.004202533967367589
flightendurancetime: 0.004202533967367589

fluid: 0.004202533967367589
fluorescentnano: 0.004202533967367589
fluoride: 0.004202533967367589
foaming: 0.004202533967367589
focused: 0.004202533967367589
focusonlightningstrikeprotection: 0.004202533967367589
foldincreaseinthermalconductivityofepoxybyadd: 0.004202533967367589
followingcontractionof: 0.004202533967367589
fongh: 0.004202533967367589
foractuation: 0.004202533967367589
forbiomedicalapplica: 0.004202533967367589
forbiomedicalapplications: 0.004202533967367589
force: 0.004202533967367589
forcementshasmadeitpossibletoachievesimultaneousimprove: 0.004202533967367589
fordamagedetectionincompositestructureshavebeenreported: 0.004202533967367589
fordispensingdrugsanddiagnostics: 0.004202533967367589
forembeddedenergystorage: 0.004202533967367589
forest: 0.004202533967367589
formed: 0.004202533967367589
formednanosilicatotheepoxymatrixresultedin: 0.004202533967367589
formonitoringstrainandcorrosion: 0.004202533967367589
formoreanalyticalmodelingworkinmostoftheareascoveredin: 0.004202533967367589
formulation: 0.004202533967367589
forsensingandactuationhavebeenthesubjectof: 0.004202533967367589
forsensornetworksinshmwerereviewedbyparketal: 0.004202533967367589
forspacesatellites: 0.004202533967367589
forth: 0.004202533967367589
forthermaltransport: 0.004202533967367589
forthermoplasticpolymers: 0.004202533967367589
foundthatthethrough: 0.004202533967367589
foundto: 0.004202533967367589
four: 0.004202533967367589
fracturebehavior: 0.004202533967367589
fracturetestingofaself: 0.004202533967367589
fracturetoughnesstestisdefinedas: 0.004202533967367589
fracturetoughnessusinganontoxicsolvent: 0.004202533967367589
frame: 0.004202533967367589
friedrichk: 0.004202533967367589
fromarttoscience: 0.004202533967367589
frombacterialsourcesreinforcedbynanoclayparticleshavebeen: 0.004202533967367589
fromcoast: 0.004202533967367589
fromcoasttocoastandaroundtheworld: 0.004202533967367589
fromvibratingstructuressuchasbeamsandplatestoelectricalen: 0.004202533967367589
frp: 0.004202533967367589
fuchs: 0.004202533967367589
fukushima: 0.004202533967367589
full: 0.004202533967367589
fullrecoveryofvirginfracturetoughness: 0.004202533967367589
funct: 0.004202533967367589
functionalize: 0.004202533967367589
functionally: 0.004202533967367589
functionsincludeelectricaland: 0.004202533967367589
functmater2008: 0.004202533967367589

furtheranalysisofthisequationforchangein: 0.004202533967367589
furtherincreasesininterleafthickness: 0.004202533967367589
furtherintegrationwas: 0.004202533967367589
furtherstudiesandapplications: 0.004202533967367589
future: 0.004202533967367589
fuzzyfiber: 0.004202533967367589
gaceva: 0.004202533967367589
gacevag: 0.004202533967367589
ganguli: 0.004202533967367589
gangulietal: 0.004202533967367589
gangulis: 0.004202533967367589
gaol: 0.004202533967367589
garcia: 0.004202533967367589
garnierb: 0.004202533967367589
gatedthehollowpiezoelectricfiberconceptinfig: 0.004202533967367589
geetha: 0.004202533967367589
geethaetal: 0.004202533967367589
generationairframes: 0.004202533967367589
gentileg: 0.004202533967367589
georgej: 0.004202533967367589
gestionsregardingfutureresearchneedsarealsopresented: 0.004202533967367589
gianarisnj: 0.004202533967367589
gibsonetal: 0.004202533967367589
gibsonr: 0.004202533967367589
gibsont: 0.004202533967367589
gin: 0.004202533967367589
gineering: 0.004202533967367589
gion: 0.004202533967367589
giurgiutiu: 0.004202533967367589
glassfacesheetsarecon: 0.004202533967367589
globaladvmaterproceng: 0.004202533967367589
gmbh: 0.004202533967367589
goldbergaj: 0.004202533967367589
goldsmith: 0.004202533967367589
golimowski: 0.004202533967367589
goransson: 0.004202533967367589
gp: 0.004202533967367589
gradedmaterials: 0.004202533967367589
gradual: 0.004202533967367589
granstromj: 0.004202533967367589
grated: 0.004202533967367589
gratedstructuralandnon: 0.004202533967367589
greater: 0.004202533967367589
greaterthan: 0.004202533967367589
greatest: 0.004202533967367589
greatinterest: 0.004202533967367589
greatly: 0.004202533967367589
grew: 0.004202533967367589
group: 0.004202533967367589
growalignedcntforestsperpendiculartothesurfaceof2dwoven: 0.004202533967367589
growing: 0.004202533967367589
growthin: 0.004202533967367589
grozdanova: 0.004202533967367589

guided: 0.004202533967367589
gun: 0.004202533967367589
guo: 0.004202533967367589
guoz: 0.004202533967367589
guptamc: 0.004202533967367589
guzmandeviloriar: 0.004202533967367589
g¼: 0.004202533967367589
haglund: 0.004202533967367589
haglundetal: 0.004202533967367589
hagood: 0.004202533967367589
hagoodnw: 0.004202533967367589
hanced: 0.004202533967367589
hanw: 0.004202533967367589
hanx: 0.004202533967367589
hartletal: 0.004202533967367589
hasmadeitpossible: 0.004202533967367589
havar: 0.004202533967367589
havealreadybeensummarizedintheprevioussection: 0.004202533967367589
haveap: 0.004202533967367589
havebeenreviewedbybirmanand: 0.004202533967367589
havebeenreviewedbyparketal: 0.004202533967367589
havere: 0.004202533967367589
havereviewedrecentpubli: 0.004202533967367589
havereviewedthedevelopmentsinmul: 0.004202533967367589
havereviewedtheliteratureintheareaofpolymernanocomposite: 0.004202533967367589
haveusedfiniteelementmodelstostudyamulti: 0.004202533967367589
hayashi: 0.004202533967367589
haywood: 0.004202533967367589
haywoodj: 0.004202533967367589
hc: 0.004202533967367589
healant: 0.004202533967367589
healedepoxyspecimensusingthetapered: 0.004202533967367589
healedspecimens: 0.004202533967367589
healedspecimensandmaximumhealing: 0.004202533967367589
healingagentinthemicrocapsuleswithepoxy: 0.004202533967367589
healingagenttoleakintothecrackbycapillaryaction: 0.004202533967367589
healingbehaviorofamatrixcrackonacarbon: 0.004202533967367589
healingcarbonfibrereinforcedpolymerfor: 0.004202533967367589
healingitselfwhendamaged: 0.004202533967367589
healingmechanicswith: 0.004202533967367589
healingpolymer: 0.004202533967367589
healingpolymercomposites: 0.004202533967367589
healingpolymericmateri: 0.004202533967367589
healingpolymericmaterials: 0.004202533967367589
healingpolymers: 0.004202533967367589
healingsystem: 0.004202533967367589
healingwovenglass: 0.004202533967367589
heating: 0.004202533967367589
heatstorage: 0.004202533967367589
hedinne: 0.004202533967367589
helicopter: 0.004202533967367589
hemp: 0.004202533967367589
henshawetal: 0.004202533967367589

henshawjm: 0.004202533967367589
hensive: 0.004202533967367589
hex: 0.004202533967367589
highaspectratiocnts: 0.004202533967367589
highest: 0.004202533967367589
highly: 0.004202533967367589
highstiff: 0.004202533967367589
hinrichsen: 0.004202533967367589
ho: 0.004202533967367589
hodgkissw: 0.004202533967367589
hollowpiezoelectricfiberwithradialpolingandlongitudinalactuationof: 0.004202533967367589
homepage: 0.004202533967367589
hon: 0.004202533967367589
hong: 0.004202533967367589
host: 0.004202533967367589
huangy: 0.004202533967367589
hubbard: 0.004202533967367589
hui: 0.004202533967367589
human: 0.004202533967367589
hyeon: 0.004202533967367589
hygrothermal: 0.004202533967367589
hyun: 0.004202533967367589
ible: 0.004202533967367589
iblepvdfpiezoelectricstraps: 0.004202533967367589
ic: 0.004202533967367589
ical: 0.004202533967367589
ically: 0.004202533967367589
icp: 0.004202533967367589
idea: 0.004202533967367589
identification: 0.004202533967367589
identificationandhealthmonitoringforcompositestructures: 0.004202533967367589
ieeetranscomponpackag: 0.004202533967367589
iesonpolymer: 0.004202533967367589
ifacompositeistobebiodegradable: 0.004202533967367589
igtknowledgecenterattheuni: 0.004202533967367589
iii: 0.004202533967367589
illus: 0.004202533967367589
illustrates: 0.004202533967367589
illustration: 0.004202533967367589
illustrationoffuzzyfiberreinforcedplastic: 0.004202533967367589
illustrationofmultifunctionalnanoparticlesystem: 0.004202533967367589
illustrationofmultilayeredmfnps: 0.004202533967367589
importantdesignconsiderationwhichhasdrivenmoredesignsto: 0.004202533967367589
importantobservationsregardingsucheffectswerereported: 0.004202533967367589
importantrolesasnon: 0.004202533967367589
improveddispersionandmechanicalpropertiesofhybrid: 0.004202533967367589
improvementofvibrationdampingcapacityand: 0.004202533967367589
improvementsinthermalconductivityofpolymers: 0.004202533967367589
inacontinuationofthiswork: 0.004202533967367589
inactivesensornetworkfor: 0.004202533967367589
inaeembeddedbetweenconventionalgraphite: 0.004202533967367589
inamultifunctionalstructure: 0.004202533967367589
inanepoxymatrix: 0.004202533967367589

inaseparatepaper: 0.004202533967367589
incarbonnanotube: 0.004202533967367589
incidentelectricfield: 0.004202533967367589
incidentmagneticfield: 0.004202533967367589
include: 0.004202533967367589
includetheuseofdifferentmethodsofhealingagentmicroencap: 0.004202533967367589
including: 0.004202533967367589
inclusionscanbeeither: 0.004202533967367589
incorporating: 0.004202533967367589
increas: 0.004202533967367589
increasedactivityintheuseofnanoparticlestoenhanceboththe: 0.004202533967367589
increaseinthermalcon: 0.004202533967367589
increaseinthermalconductiv: 0.004202533967367589
increasingly: 0.004202533967367589
increasinglyimportant: 0.004202533967367589
indi: 0.004202533967367589
indifferentphasesofflightasabirdwingdoes: 0.004202533967367589
individual: 0.004202533967367589
induced: 0.004202533967367589
induceddamagecharacterizationofcompositeplatesusingneuralnetworks: 0.004202533967367589
induceddeformationsandthosepredictedbyamodi: 0.004202533967367589
industry: 0.004202533967367589
infiltrated: 0.004202533967367589
infiltration: 0.004202533967367589
influenced: 0.004202533967367589
influencedbymultifunctionaldesignrequirements: 0.004202533967367589
ingagent: 0.004202533967367589
inglyusedtoreplacemetals: 0.004202533967367589
ingofacnt: 0.004202533967367589
ingreeningthe21stcenturymaterialsworld: 0.004202533967367589
initial: 0.004202533967367589
injection: 0.004202533967367589
ink: 0.004202533967367589
inload: 0.004202533967367589
inman: 0.004202533967367589
inmandj: 0.004202533967367589
inorganic: 0.004202533967367589
inorganicorhybridorganic: 0.004202533967367589
inresponsetothemarkedincreaseinresearchactivityandpublicationsinmultifunctionalmaterialsand: 0.004202533967367589
inself: 0.004202533967367589
insensornetworkfor: 0.004202533967367589
insitunanoparticle: 0.004202533967367589
insomecases: 0.004202533967367589
instituteofphysics: 0.004202533967367589
instrumented: 0.004202533967367589
insulator: 0.004202533967367589
insuringthedesiredlowpercolationthresholds: 0.004202533967367589
int: 0.004202533967367589
inte: 0.004202533967367589
integrates: 0.004202533967367589
integration: 0.004202533967367589
intell: 0.004202533967367589

intelligence: 0.004202533967367589
intense: 0.004202533967367589
interactionstrength: 0.004202533967367589
interconnect: 0.004202533967367589
interfacial: 0.004202533967367589
interfacialdampingcharacteristicsof: 0.004202533967367589
interferenceshielding: 0.004202533967367589
interior: 0.004202533967367589
interlayer: 0.004202533967367589
interphase: 0.004202533967367589
inthelossmodulusofpolycarbonate: 0.004202533967367589
inthiscase: 0.004202533967367589
intjdamagemech2005: 0.004202533967367589
intjfract: 0.004202533967367589
intjheatmasstransfer2008: 0.004202533967367589
intjpolymmater1997: 0.004202533967367589
intmaterrev2008: 0.004202533967367589
intrinsically: 0.004202533967367589
introductionofcarbonnanotubes: 0.004202533967367589
inversely: 0.004202533967367589
investi: 0.004202533967367589
investigateddifferentpolymer: 0.004202533967367589
investigatedthepropertiesofcommercialcarbonfabricmaterials: 0.004202533967367589
involve: 0.004202533967367589
involves: 0.004202533967367589
involving: 0.004202533967367589
involvingmodelsforfluiddynamics: 0.004202533967367589
ionbattery: 0.004202533967367589
ionbatteryinthecarbon: 0.004202533967367589
ipmc: 0.004202533967367589
isasignificantadvantageofanewclassofmaterialsknownasmag: 0.004202533967367589
iscapableofrechargingadischargednickelmetalhydridebattery: 0.004202533967367589
ischaracterizedbythepiezoelectric: 0.004202533967367589
isdefinedindecibels: 0.004202533967367589
ishighlyrel: 0.004202533967367589
isincorpo: 0.004202533967367589
islessthanacriticalvalue: 0.004202533967367589
isonlyabout104: 0.004202533967367589
issolowbecausetheextremelyhighaspectratiosofcntsmake: 0.004202533967367589
istoembednano: 0.004202533967367589
itappearsthatsodanoetal: 0.004202533967367589
itesleadtomajorimprovementsinsomepropertieswhilecausing: 0.004202533967367589
ithasbeen: 0.004202533967367589
itisappropriatetociteseveralrelevantpreviousreviewarti: 0.004202533967367589
itisimportanttode: 0.004202533967367589
itispossibletosimultaneouslyincreasestrengthandmodu: 0.004202533967367589
itors: 0.004202533967367589
itsultimatetensilestrength: 0.004202533967367589
itturnsoutthatverysmallconcentrationsofcarbonnanotubes: 0.004202533967367589
itwasfound: 0.004202533967367589
itwasfoundthattheinterfacial: 0.004202533967367589
itwasfoundthattheyoung: 0.004202533967367589
itwasnotpracticaltocoverallofthesearticles: 0.004202533967367589

itwasshownthataconventionalautoclavepro: 0.004202533967367589
ium: 0.004202533967367589
iv: 0.004202533967367589
jacobsen: 0.004202533967367589
jaerospeng2010: 0.004202533967367589
jafferisnt: 0.004202533967367589
jalili: 0.004202533967367589
japplmater2008: 0.004202533967367589
japplphys2002: 0.004202533967367589
japplphys2009: 0.004202533967367589
japplpolymsci: 0.004202533967367589
japplpolymsci2009: 0.004202533967367589
jbiobased: 0.004202533967367589
jelectrochemsoc2009: 0.004202533967367589
jengmater: 0.004202533967367589
jengmatertechnol2001: 0.004202533967367589
jia: 0.004202533967367589
jiaqm: 0.004202533967367589
jinfrastructsyst2008: 0.004202533967367589
jing: 0.004202533967367589
jintellmatersyststruct1995: 0.004202533967367589
jintellmatersyststruct2001: 0.004202533967367589
jintellmatersyststruct2005: 0.004202533967367589
jk: 0.004202533967367589
jmatersci2006: 0.004202533967367589
jmatersci2008: 0.004202533967367589
jmatersci2009: 0.004202533967367589
jn: 0.004202533967367589
jnanosci: 0.004202533967367589
johnson: 0.004202533967367589
joining: 0.004202533967367589
joint: 0.004202533967367589
jom2005: 0.004202533967367589
joshi: 0.004202533967367589
joshims: 0.004202533967367589
joung: 0.004202533967367589
jpolymenviron2005: 0.004202533967367589
jpowersources2009: 0.004202533967367589
jsand: 0.004202533967367589
jthermoplastcomposmater1996: 0.004202533967367589
july: 0.004202533967367589
jung: 0.004202533967367589
jurgas: 0.004202533967367589
jute: 0.004202533967367589
jw: 0.004202533967367589
jz: 0.004202533967367589
kalaitzidou: 0.004202533967367589
kamio: 0.004202533967367589
kamnws: 0.004202533967367589
kane: 0.004202533967367589
kanh: 0.004202533967367589
kar: 0.004202533967367589
karger: 0.004202533967367589

karlsson: 0.004202533967367589
ka¼: 0.004202533967367589
keblinski: 0.004202533967367589
kempak: 0.004202533967367589
kesslermr: 0.004202533967367589
keyengmater1998: 0.004202533967367589
keyengmater2010: 0.004202533967367589
keywords: 0.004202533967367589
kh: 0.004202533967367589
kiefferj: 0.004202533967367589
kimetal: 0.004202533967367589
kimhs: 0.004202533967367589
kinloch: 0.004202533967367589
kinlochaj: 0.004202533967367589
kinlochia: 0.004202533967367589
kinslowr: 0.004202533967367589
kinslowrw: 0.004202533967367589
kirkje: 0.004202533967367589
kirkjg: 0.004202533967367589
kj: 0.004202533967367589
kk: 0.004202533967367589
kks: 0.004202533967367589
klompenetj: 0.004202533967367589
kn: 0.004202533967367589
kocsisj: 0.004202533967367589
kong: 0.004202533967367589
koratkaretal: 0.004202533967367589
koratkarna: 0.004202533967367589
kovacs: 0.004202533967367589
koyk: 0.004202533967367589
krawczak: 0.004202533967367589
kudva: 0.004202533967367589
kudvaj: 0.004202533967367589
kudvajn: 0.004202533967367589
kumara: 0.004202533967367589
kumarr: 0.004202533967367589
kumem: 0.004202533967367589
kwon: 0.004202533967367589
la: 0.004202533967367589
lacrampe: 0.004202533967367589
laimo: 0.004202533967367589
lajolla: 0.004202533967367589
laminated: 0.004202533967367589
laminatedstructuresbysrivastavaetal: 0.004202533967367589
laminatesbasedonthecrackclosuretechniqueforfiberbridging: 0.004202533967367589
language: 0.004202533967367589
largerangesofdeformation: 0.004202533967367589
latedtothedevelopmentofmfnpsforcancerimagingandtherapy: 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
limiting: 0.004202533967367589
lin: 0.004202533967367589
linandchang: 0.004202533967367589
linm: 0.004202533967367589
lished: 0.004202533967367589
listed: 0.004202533967367589
lithiumenergycellswithincarbon: 0.004202533967367589
liud: 0.004202533967367589
liuy: 0.004202533967367589
liwz: 0.004202533967367589
llaguno: 0.004202533967367589
loadsupport: 0.004202533967367589
locate: 0.004202533967367589
lockyer: 0.004202533967367589
lockyera: 0.004202533967367589
lockyeraj: 0.004202533967367589
logic: 0.004202533967367589
loh: 0.004202533967367589
lohetal: 0.004202533967367589
lohkj: 0.004202533967367589
lonettip: 0.004202533967367589
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
lowerpercolationthresholdthanthecompositescontainingpani: 0.004202533967367589
lowpercolationthresholdsas: 0.004202533967367589
luchtb: 0.004202533967367589
luoandchung: 0.004202533967367589
luox: 0.004202533967367589
lynch: 0.004202533967367589
lynchjp: 0.004202533967367589
lyonsjrk: 0.004202533967367589
macro: 0.004202533967367589
macromolmater: 0.004202533967367589
magneticallysusceptibleparticlesformagneticresonance: 0.004202533967367589
magnetizable: 0.004202533967367589
magnetorheological: 0.004202533967367589
mai: 0.004202533967367589
maia: 0.004202533967367589
mailaddress: 0.004202533967367589
maintaining: 0.004202533967367589
maitis: 0.004202533967367589
makesoptimizationofsuchsystemsanevengreaterchallenge: 0.004202533967367589
making: 0.004202533967367589
malconditions: 0.004202533967367589
malinconicom: 0.004202533967367589
malinsulation: 0.004202533967367589
mally: 0.004202533967367589
manage: 0.004202533967367589
management: 0.004202533967367589
manager: 0.004202533967367589
manipulation: 0.004202533967367589
manjunathacm: 0.004202533967367589
manual: 0.004202533967367589
manuf2001: 0.004202533967367589
manuf2010: 0.004202533967367589
manufacture: 0.004202533967367589
manufacturingandreliabilityoftheactivecomposites: 0.004202533967367589
mariattim: 0.004202533967367589
markedly: 0.004202533967367589
mater2006: 0.004202533967367589
mater2009: 0.004202533967367589
materbioenergy2008: 0.004202533967367589
materconf2001: 0.004202533967367589
materconference: 0.004202533967367589
materialincarbonfiber: 0.004202533967367589
materialsandstructureshassteadilyincreasedsince2000: 0.004202533967367589
materialshas: 0.004202533967367589
materialssuchasleadzir: 0.004202533967367589
matersci2001: 0.004202533967367589

materscieng2008: 0.004202533967367589
materstruct2005: 0.004202533967367589
matertoday2007: 0.004202533967367589
mateti: 0.004202533967367589
matherpt: 0.004202533967367589
mationservice: 0.004202533967367589
matrixinterfacialshearstrength: 0.004202533967367589
matrixmaterialsmadefromrenewableresourcesareobviouslyof: 0.004202533967367589
matsuzakir: 0.004202533967367589
mav: 0.004202533967367589
maxi: 0.004202533967367589
mayes: 0.004202533967367589
mc: 0.004202533967367589
mcalpinemc: 0.004202533967367589
mccarvilleda: 0.004202533967367589
mckinstry: 0.004202533967367589
mea: 0.004202533967367589
mean: 0.004202533967367589
measscitechnol2009: 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
mendomer: 0.004202533967367589
mendomercomposite: 0.004202533967367589
meng: 0.004202533967367589
mentand: 0.004202533967367589
mentsfornaturalfiberscanreducetheirsensitivitytohygrother: 0.004202533967367589
mentsinthemodeiandmodeiifracturetoughnesses: 0.004202533967367589
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
mfnpswhichhaveacom: 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
minorreductionsinotherproperties: 0.004202533967367589
misra: 0.004202533967367589
misram: 0.004202533967367589
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
mohanty: 0.004202533967367589
mohantyak: 0.004202533967367589
mohwaldh: 0.004202533967367589
moleculardynamicssimulationtoshowthatifthepolymer: 0.004202533967367589
monitored: 0.004202533967367589
monitorforacompositepanelemployingsmartsensortechnology: 0.004202533967367589
monomer: 0.004202533967367589
montalvao: 0.004202533967367589
montalvaoetal: 0.004202533967367589
monte: 0.004202533967367589
mooneyjt: 0.004202533967367589
moore: 0.004202533967367589
moosbruggerjc: 0.004202533967367589
moreflexibilityinuseofthestoredenergy: 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
mre: 0.004202533967367589
mri: 0.004202533967367589
mrsbull2007: 0.004202533967367589
mrsbull2009: 0.004202533967367589
mudupuv: 0.004202533967367589
multidisciplinary: 0.004202533967367589

multifunctionalcompositematerialsandstructuresandreviewrepresentativejournalpublicationsthat: 0.004202533967367589
multifunctionalcomposites: 0.004202533967367589
multifunctionalcompositestructures: 0.004202533967367589
multifunctionallayer: 0.004202533967367589
multifunctionalmagnetic: 0.004202533967367589
multifunctionalmaterialsandstructuresarethoseinthebiomed: 0.004202533967367589
multifunctionalmaterialsandstructurestendtobeoftype: 0.004202533967367589
multifunctionalnanosystemsattheinterfaceof: 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
naiks: 0.004202533967367589
nanocom: 0.004202533967367589
nanocompositematrixforincreased: 0.004202533967367589
nanocompositesandhybridmultiscalecompositescontainingboth: 0.004202533967367589
nanocompositestructuresforaerospaceapplications: 0.004202533967367589
nanofibers2796: 0.004202533967367589
nanofibersornanotubesandothernano: 0.004202533967367589
nanofillers: 0.004202533967367589
nanofoam: 0.004202533967367589
nanolett2004: 0.004202533967367589
nanolett2008: 0.004202533967367589
nanomaterialsandnanostructures: 0.004202533967367589
nanomedicaldevices: 0.004202533967367589
nanometer: 0.004202533967367589
nanometerscalethicknessesonrubbersubstrates: 0.004202533967367589
nanoparticlereinforcementofthematrixinaunidirectionalfibercomposite: 0.004202533967367589
nanoporous: 0.004202533967367589
nanoreinforcementslikecarbonnanotubesonthesurfaceofthefi: 0.004202533967367589
nanoscalereslett2008: 0.004202533967367589
nanosci: 0.004202533967367589
nanosci2007: 0.004202533967367589
nanosilica: 0.004202533967367589
nanostruc: 0.004202533967367589
nanostructureshavebeenreviewedbylou: 0.004202533967367589
nanotechnol: 0.004202533967367589
nanotechnol2007: 0.004202533967367589
nanotechnology2007: 0.004202533967367589
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
necessarily: 0.004202533967367589
nected: 0.004202533967367589
need: 0.004202533967367589
ness: 0.004202533967367589
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
occurswhenanundesirable: 0.004202533967367589
of2808: 0.004202533967367589
ofalignedcntforeststoconventionalfibercompositeshavebeen: 0.004202533967367589
ofamicrostripantennawhichisintegratedinathreedimensional: 0.004202533967367589
ofastructurallyintegratedconformalload: 0.004202533967367589
offertheadvantageofloweroperatingvoltageanda: 0.004202533967367589
office: 0.004202533967367589
ofipmcs: 0.004202533967367589
ofprovidingitsownnoiseandvibrationcontrol: 0.004202533967367589
ofrecentarticlesonconductivityandemishieldingcharacteristics: 0.004202533967367589
ofsuchalblsensoronaminiatureplanarcoilantennaresultsina: 0.004202533967367589
oftenconsistofcompositefacesheetsandfoamcores: 0.004202533967367589
ofthecorrespondingvaluesforthe: 0.004202533967367589
ofthenanocomposite: 0.004202533967367589
ofthesetechnologiesisformorphingaircraftskins: 0.004202533967367589
ofthisreview: 0.004202533967367589
ofvariablestrengthwasusedtocontinuouslyandrapidlycontrol: 0.004202533967367589
ofvirginepoxyandself: 0.004202533967367589
old: 0.004202533967367589
olekm: 0.004202533967367589
oncarbonfibers: 0.004202533967367589
ondatacollectedfromtheengineeringvillage: 0.004202533967367589

onedrawbackto: 0.004202533967367589
onemajorgoalofsuchresearchis: 0.004202533967367589
onepopularapplicationistopowersmallelectronicdevices: 0.004202533967367589
onesuch: 0.004202533967367589
oneveryimportantapplica: 0.004202533967367589
onexperimentalwork: 0.004202533967367589
online: 0.004202533967367589
onlinefirst: 0.004202533967367589
onmaterialsforemi: 0.004202533967367589
onmetallicconductors: 0.004202533967367589
onmethodsandmaterialsforemi: 0.004202533967367589
onpolymericmatrixcomposites: 0.004202533967367589
onshapememorypolymerswhichhavepotentialapplicationsas: 0.004202533967367589
onthesurfaceofcarbonfibersusingchemicalvapordepo: 0.004202533967367589
onto: 0.004202533967367589
ooitk: 0.004202533967367589
open: 0.004202533967367589
optically: 0.004202533967367589
opticallytransparent: 0.004202533967367589
optimization: 0.004202533967367589
optimized: 0.004202533967367589
optimum: 0.004202533967367589
oractuators: 0.004202533967367589
orbefilledwithaconductingmaterialsuchascarbonfibers: 0.004202533967367589
ordeformationofahoststructureand: 0.004202533967367589
order: 0.004202533967367589
ordersofmagnitudewhenalignedmwnt: 0.004202533967367589
orenhancemultifunction: 0.004202533967367589
organosilicasol: 0.004202533967367589
orientationandmechanicalproperties: 0.004202533967367589
orientedpublications: 0.004202533967367589
original: 0.004202533967367589
oritsmissionprofilechangeshasbeenasubjectofgreat: 0.004202533967367589
ormorphitselfasitsoperatingenviron: 0.004202533967367589
ornetal: 0.004202533967367589
ostranderj: 0.004202533967367589
otherrecentdevelopmentsinself: 0.004202533967367589
ous: 0.004202533967367589
oussectionisalsohighlyrelevanttoenergyharvesting: 0.004202533967367589
outer: 0.004202533967367589
over90: 0.004202533967367589
overall: 0.004202533967367589
overviewofrecyclingissuesforcomposite: 0.004202533967367589
overviewoftheairforcesmartskin: 0.004202533967367589
owensad: 0.004202533967367589
ozakietal: 0.004202533967367589
ozakit: 0.004202533967367589
pact: 0.004202533967367589
pan: 0.004202533967367589
pandey: 0.004202533967367589
pandeyjk: 0.004202533967367589
panifibers: 0.004202533967367589
paniparticles: 0.004202533967367589

paniwires: 0.004202533967367589
parameter: 0.004202533967367589
parasitically: 0.004202533967367589
parkjs: 0.004202533967367589
partg: 0.004202533967367589
partially: 0.004202533967367589
particleinteractionstrengthisgreaterthanthepolymer: 0.004202533967367589
particleinterfaceandtheyoung: 0.004202533967367589
particlesonthetensilefatiguebehaviorofaglassfibreepoxy: 0.004202533967367589
particular: 0.004202533967367589
particularlypolymericmaterials: 0.004202533967367589
patch: 0.004202533967367589
patelaj: 0.004202533967367589
payloadsubsystemweight: 0.004202533967367589
pcinterfaces: 0.004202533967367589
pcnanocompositesatdifferent: 0.004202533967367589
peek: 0.004202533967367589
peijs: 0.004202533967367589
peijst: 0.004202533967367589
percentageofresistancechange: 0.004202533967367589
percola: 0.004202533967367589
percolationincarbonnanotubecomposites: 0.004202533967367589
pereira: 0.004202533967367589
pereiraetal: 0.004202533967367589
pereirat: 0.004202533967367589
perform: 0.004202533967367589
perform2000: 0.004202533967367589
period: 0.004202533967367589
permission: 0.004202533967367589
perspective: 0.004202533967367589
petersongp: 0.004202533967367589
peutics: 0.004202533967367589
pfc: 0.004202533967367589
ph: 0.004202533967367589
photomicrograph: 0.004202533967367589
physicalandlifesciences: 0.004202533967367589
pickensj: 0.004202533967367589
pie: 0.004202533967367589
piezoceramic: 0.004202533967367589
piezoceramichollowfiberactivecomposites: 0.004202533967367589
piezoelectriccomposites: 0.004202533967367589
piezoelectriccouplingcoefficientforactuation: 0.004202533967367589
piezoelectriccouplingcoefficientforsensing: 0.004202533967367589
piezoelectricmicroelectromechanical: 0.004202533967367589
piezoelectricstructuralfiber: 0.004202533967367589
piezoelectricstructuralfiberformultifunctionalcomposites: 0.004202533967367589
piezolectric: 0.004202533967367589
pile: 0.004202533967367589
pineappleleaffibers: 0.004202533967367589
piotrowska: 0.004202533967367589
piotrowskaetal: 0.004202533967367589
pipe: 0.004202533967367589
pipesandwichpanelstructure: 0.004202533967367589

pitch: 0.004202533967367589
placedthenylonshoulderstrapsonastandardbackpackwithflex: 0.004202533967367589
plane: 0.004202533967367589
plast: 0.004202533967367589
ple: 0.004202533967367589
plied: 0.004202533967367589
plotner: 0.004202533967367589
pmma: 0.004202533967367589
polcawich: 0.004202533967367589
poling: 0.004202533967367589
polingresults: 0.004202533967367589
polyaniline: 0.004202533967367589
polycarbonate: 0.004202533967367589
polycarbonatecomposites: 0.004202533967367589
polyelectrolyte: 0.004202533967367589
polyelectrolytethinfilmsforstrainandcorrosionsensing: 0.004202533967367589
polymadvtechnol2005: 0.004202533967367589
polymcompos2004: 0.004202533967367589
polymer2008: 0.004202533967367589
polymerblendsandcompositesfromrenewableresources: 0.004202533967367589
polymercompos: 0.004202533967367589
polymercompos2007: 0.004202533967367589
polymerconductivecomposites: 0.004202533967367589
polymericcompositeswithmicroandnanoparticles: 0.004202533967367589
polymerization: 0.004202533967367589
polymermatrixcompositesascapacitors: 0.004202533967367589
polymermatrixcompositessuchastheoneinfig: 0.004202533967367589
polymernanocompositefoams: 0.004202533967367589
polymersandpolymercompositesbasedontheuseofamicroen: 0.004202533967367589
polymersci: 0.004202533967367589
polymerslead: 0.004202533967367589
polypropylene: 0.004202533967367589
polystyrenewithnoeffectonitstransparency: 0.004202533967367589
polyvinylidene: 0.004202533967367589
poorly: 0.004202533967367589
poorpar: 0.004202533967367589
pore: 0.004202533967367589
porous: 0.004202533967367589
ported: 0.004202533967367589
pose: 0.004202533967367589
positelaminate: 0.004202533967367589
positelaminatesbecauseoftheweakmatrixresin: 0.004202533967367589
positewasfoundtoexhibitsimultaneousandsignificantimprove: 0.004202533967367589
potterk: 0.004202533967367589
powder: 0.004202533967367589
powerharvestingdevices: 0.004202533967367589
poweringmemsportabledevices: 0.004202533967367589
ppy: 0.004202533967367589
practical: 0.004202533967367589
pratheepkumara: 0.004202533967367589
previous: 0.004202533967367589
previouslydevelopedsic: 0.004202533967367589
primarily: 0.004202533967367589

principle: 0.004202533967367589
printed160lm: 0.004202533967367589
printedcircuiton: 0.004202533967367589
printing: 0.004202533967367589
privman: 0.004202533967367589
probe: 0.004202533967367589
proc: 0.004202533967367589
proc2008sampefall: 0.004202533967367589
proc34thaiaastructures: 0.004202533967367589
proceeding: 0.004202533967367589
procinstmech: 0.004202533967367589
procintsampesympexhib: 0.004202533967367589
procintsampesymposiumandexhibition: 0.004202533967367589
procintsampetech: 0.004202533967367589
procintsampetechconf: 0.004202533967367589
procspiesmartstruct: 0.004202533967367589
procspiesmartstructmaterconf1996: 0.004202533967367589
production: 0.004202533967367589
prog: 0.004202533967367589
progmater: 0.004202533967367589
progpolymsci: 0.004202533967367589
progpolymsci2008: 0.004202533967367589
programintends: 0.004202533967367589
projectile: 0.004202533967367589
promising: 0.004202533967367589
propelled: 0.004202533967367589
propellerefficiency: 0.004202533967367589
propertiesofahybridlaminatewithalignedcarbonnanotubesgrowninsitu: 0.004202533967367589
proportional: 0.004202533967367589
proportionatelylargeimprovementsintheelectricalconductivity: 0.004202533967367589
propulsionsubsystemweight: 0.004202533967367589
propulsionsystems: 0.004202533967367589
protection: 0.004202533967367589
protein: 0.004202533967367589
proveseveralproperties: 0.004202533967367589
providing: 0.004202533967367589
pub: 0.004202533967367589
publicationsdealingwith: 0.004202533967367589
publicationson: 0.004202533967367589
publicationsre: 0.004202533967367589
publishedbyal: 0.004202533967367589
publishedonlinefirstjanuary28: 0.004202533967367589
pur: 0.004202533967367589
putthanarats: 0.004202533967367589
pv: 0.004202533967367589
pvdf: 0.004202533967367589
qidwai: 0.004202533967367589
qidwaima: 0.004202533967367589
qietal: 0.004202533967367589
qiuj: 0.004202533967367589
qiy: 0.004202533967367589
qm: 0.004202533967367589
qsc3: 0.004202533967367589

quadrilateral: 0.004202533967367589
queheillalt: 0.004202533967367589
queheillaltdt: 0.004202533967367589
quick: 0.004202533967367589
quired: 0.004202533967367589
qul: 0.004202533967367589
r1: 0.004202533967367589
radiallyalignedcntsgrownonadvancedfibercloth: 0.004202533967367589
radiation: 0.004202533967367589
radiator: 0.004202533967367589
radius: 0.004202533967367589
radosavljevic: 0.004202533967367589
rahmqvist: 0.004202533967367589
rajoria: 0.004202533967367589
rajoriaandjalili: 0.004202533967367589
rakovichyp: 0.004202533967367589
ramakrishnaetal: 0.004202533967367589
ramakrishnas: 0.004202533967367589
ramie: 0.004202533967367589
rao: 0.004202533967367589
rate: 0.004202533967367589
ratecomponents: 0.004202533967367589
ratedintheepoxyadhesive: 0.004202533967367589
ratelydescribesthistransitionbyequation: 0.004202533967367589
ratherthantakingthetraditionalapproachoftreating: 0.004202533967367589
ratnad: 0.004202533967367589
ray: 0.004202533967367589
reacts: 0.004202533967367589
reasonably: 0.004202533967367589
received: 0.004202533967367589
recentadvancesinshapememorypolymersand: 0.004202533967367589
recentapplicationsofmultifunctionalmaterialsand: 0.004202533967367589
recentapplicationsofmultifunctionalmaterialsandstructures: 0.004202533967367589
recentdevelopments: 0.004202533967367589
recentdevelopmentsinself: 0.004202533967367589
recentenglishlanguagerefereedjournalarticlesrelatedtomultifunctional: 0.004202533967367589
recentenglishlanguagerefereedjournalpublicationsrelatedtomultifunc: 0.004202533967367589
recentpublicationsonthesynthesisandappli: 0.004202533967367589
record: 0.004202533967367589
recovery: 0.004202533967367589
recy: 0.004202533967367589
recyclability: 0.004202533967367589
recyclabilityandbiodegradabil: 0.004202533967367589
recycle: 0.004202533967367589
recyclingofcarbonfiber: 0.004202533967367589
recyclingofthermoplasticcomposites: 0.004202533967367589
recyclingscenarios: 0.004202533967367589
reduc: 0.004202533967367589
reducing: 0.004202533967367589
refereed: 0.004202533967367589
refractiveindex: 0.004202533967367589
regenerativeandregenerativepowersupplysystemswith: 0.004202533967367589
rein: 0.004202533967367589

reinf: 0.004202533967367589
reinforcedcompositeshasalsobeencon: 0.004202533967367589
reinforcedepoxycomposite: 0.004202533967367589
reinfplasticscompos: 0.004202533967367589
relatedconcerns: 0.004202533967367589
relatedresearchbythe: 0.004202533967367589
relativelyeasyfor: 0.004202533967367589
relativemotionsbetweenthesoldier: 0.004202533967367589
relevant: 0.004202533967367589
renewable: 0.004202533967367589
renz: 0.004202533967367589
renzf: 0.004202533967367589
repair: 0.004202533967367589
repeated: 0.004202533967367589
replaced: 0.004202533967367589
replacement: 0.004202533967367589
replacing: 0.004202533967367589
replacingtheneatresinpolymermatrixwithananocompositema: 0.004202533967367589
report: 0.004202533967367589
reporteda57: 0.004202533967367589
reportedonmultifunctionalsand: 0.004202533967367589
reportedthata3: 0.004202533967367589
reportedthatmul: 0.004202533967367589
reportedultra: 0.004202533967367589
reportsontheuseofartificialneuralnetworks: 0.004202533967367589
requirement: 0.004202533967367589
requirementsinthedesignofmultifunctionalcomposites: 0.004202533967367589
requires: 0.004202533967367589
researchinterestinrecentyears: 0.004202533967367589
researchonnaturalfiberssuchas: 0.004202533967367589
resistanceand: 0.004202533967367589
resistanceofinkjet: 0.004202533967367589
resource: 0.004202533967367589
resultingimproveddispersionofsilicananoparticlesintheepoxy: 0.004202533967367589
retardation: 0.004202533967367589
reusable: 0.004202533967367589
reviewarticle: 0.004202533967367589
reviewarticlebybystrzejewski: 0.004202533967367589
reviewedarti: 0.004202533967367589
revieweddevelopmentsintheappli: 0.004202533967367589
reviewedrecentadvances: 0.004202533967367589
reviewedrecentstud: 0.004202533967367589
reviewedthechallenges: 0.004202533967367589
reviewedvibration: 0.004202533967367589
rf: 0.004202533967367589
rg: 0.004202533967367589
rialsrequiresubstantialflexibilityinordertoaccommodatelarge: 0.004202533967367589
ribeiro: 0.004202533967367589
richregionsthat: 0.004202533967367589
robotarms: 0.004202533967367589
robust: 0.004202533967367589
rogersjp: 0.004202533967367589
rojanapitayak: 0.004202533967367589

rojanapitayakornp: 0.004202533967367589
rollmillprocessinducesintenseshearmix: 0.004202533967367589
ronald: 0.004202533967367589
ronaldgibson: 0.004202533967367589
rongmz: 0.004202533967367589
room: 0.004202533967367589
rosingt: 0.004202533967367589
roy: 0.004202533967367589
royak: 0.004202533967367589
s3td: 0.004202533967367589
salehandsundararaj: 0.004202533967367589
sampe: 0.004202533967367589
sampej2005: 0.004202533967367589
sampej2008: 0.004202533967367589
sample: 0.004202533967367589
sandleretal: 0.004202533967367589
sandlerjkw: 0.004202533967367589
sandwiched: 0.004202533967367589
sandwichisusedtoreplaceatraditionalroofpanelwithitssepa: 0.004202533967367589
sandwichstructureinwhichthewovene: 0.004202533967367589
sandwichstructures: 0.004202533967367589
sastryam: 0.004202533967367589
satellite: 0.004202533967367589
sbodyandthebackpackgen: 0.004202533967367589
schadler: 0.004202533967367589
sci2005: 0.004202533967367589
scienceandtechnologyofcarbonnanotubecomposites: 0.004202533967367589
scientificresearch: 0.004202533967367589
seale: 0.004202533967367589
searchrelatedtotheclashasinvolvedthedesignandfabrication: 0.004202533967367589
see: 0.004202533967367589
seefig: 0.004202533967367589
seefrontmatter: 0.004202533967367589
seetharamakn: 0.004202533967367589
seisparticularlyimportantformul: 0.004202533967367589
sekinek: 0.004202533967367589
select: 0.004202533967367589
selected: 0.004202533967367589
selectedpapers: 0.004202533967367589
sely: 0.004202533967367589
sensactuators: 0.004202533967367589
sensingorenergyharvesting: 0.004202533967367589
sensitive: 0.004202533967367589
sensitivity: 0.004202533967367589
sensormultifunctional: 0.004202533967367589
sensorsand: 0.004202533967367589
sensorsystem: 0.004202533967367589
september: 0.004202533967367589
september8: 0.004202533967367589
series: 0.004202533967367589
serve: 0.004202533967367589
service: 0.004202533967367589
servicethroughthemathewson: 0.004202533967367589

setting: 0.004202533967367589
severalrelevantapplications: 0.004202533967367589
severalsug: 0.004202533967367589
se¼20log: 0.004202533967367589
sh: 0.004202533967367589
shaffermsp: 0.004202533967367589
shahinpoor: 0.004202533967367589
shahinpoorandkimhavepublished: 0.004202533967367589
shang: 0.004202533967367589
shankarc: 0.004202533967367589
sharp: 0.004202533967367589
shearstrengthofthemodifiedcarbonfiberswas15: 0.004202533967367589
shellcompositeparticles: 0.004202533967367589
shen: 0.004202533967367589
shenj: 0.004202533967367589
shenogin: 0.004202533967367589
shenogina: 0.004202533967367589
shenoginaet: 0.004202533967367589
sherman: 0.004202533967367589
shieldingcharacteristicsofcarbonnanofiber: 0.004202533967367589
shieldingmaterialorstructure: 0.004202533967367589
shine: 0.004202533967367589
shockvibdigest2004: 0.004202533967367589
shockvibdigest2006: 0.004202533967367589
shoulder: 0.004202533967367589
showninfig: 0.004202533967367589
showshowthepercolationthresh: 0.004202533967367589
showthat: 0.004202533967367589
si: 0.004202533967367589
sidered: 0.004202533967367589
significantimprovementinim: 0.004202533967367589
significantly: 0.004202533967367589
significantreductionsinthestoragemoduluswhenthepcwasen: 0.004202533967367589
sihnetal: 0.004202533967367589
sihns: 0.004202533967367589
silicate: 0.004202533967367589
silver: 0.004202533967367589
similar: 0.004202533967367589
similarly: 0.004202533967367589
similarsystemshavebeenadaptedforcontrolofsmart: 0.004202533967367589
simpler: 0.004202533967367589
since2000therehasbeenasurgeinthenumberofjournal: 0.004202533967367589
sincemostofthepublicationstodateinvolveexperimentalwork: 0.004202533967367589
sincemostofthepublishedresultstodatetendtobe: 0.004202533967367589
singhr: 0.004202533967367589
sionofelectricalenergytomechanicalenergy: 0.004202533967367589
sireuded: 0.004202533967367589
sisalfibersandtheirbiocomposites: 0.004202533967367589
sisinthissectionwillbeonrecentdevelopmentsinenergystorage: 0.004202533967367589
sisissupportedbytheanalysisofzhouetal: 0.004202533967367589
sisofthepublicationssurveyedwillbeonthemechanicsaspects: 0.004202533967367589
site: 0.004202533967367589
sition: 0.004202533967367589

sitionofdissimilarthinfilmsatthenanoscale: 0.004202533967367589
situ: 0.004202533967367589
sizedfibershasalsobeenthesubjectofnumer: 0.004202533967367589
sizedparticle: 0.004202533967367589
sizewasreducedinthenanorange: 0.004202533967367589
sj: 0.004202533967367589
skinstructuretechnologydemonstration: 0.004202533967367589
sliding: 0.004202533967367589
slip: 0.004202533967367589
slower: 0.004202533967367589
sm: 0.004202533967367589
smartcompositematerials: 0.004202533967367589
smartmater: 0.004202533967367589
smartmaterstruct2001: 0.004202533967367589
smartmaterstruct2003: 0.004202533967367589
smartmaterstruct2004: 0.004202533967367589
smartmaterstruct2005: 0.004202533967367589
smartmaterstruct2008: 0.004202533967367589
smodulus: 0.004202533967367589
smodulusincreased: 0.004202533967367589
smodulusofthenanocomposite: 0.004202533967367589
smoduluswasnotaffected: 0.004202533967367589
smp: 0.004202533967367589
snyder: 0.004202533967367589
snyderjf: 0.004202533967367589
socforadvofmaterandprocesseng: 0.004202533967367589
soinorder: 0.004202533967367589
sokolov: 0.004202533967367589
sokolovi: 0.004202533967367589
solar: 0.004202533967367589
soldano: 0.004202533967367589
solomond: 0.004202533967367589
solventmicrocap: 0.004202533967367589
somearticleshadalreadybeencoveredbypreviousrelatedreview: 0.004202533967367589
song: 0.004202533967367589
songetal: 0.004202533967367589
songj: 0.004202533967367589
sothatisthefocus: 0.004202533967367589
sottos: 0.004202533967367589
soundvib2000: 0.004202533967367589
space: 0.004202533967367589
spacecraftrockets2002: 0.004202533967367589
speci: 0.004202533967367589
special: 0.004202533967367589
specialemphasisonpiezoelectricenergyharvestingsystems: 0.004202533967367589
specimen: 0.004202533967367589
specimensreachedupto75: 0.004202533967367589
spherical: 0.004202533967367589
sprengers: 0.004202533967367589
sriramsr: 0.004202533967367589
srivastavaa: 0.004202533967367589
ssmart: 0.004202533967367589
stacked: 0.004202533967367589

stalticpumps: 0.004202533967367589
stamboulis: 0.004202533967367589
standtheeffectsofparticlesizeontheresultingcompositeproper: 0.004202533967367589
starkovich: 0.004202533967367589
staszewskiwj: 0.004202533967367589
statepoly: 0.004202533967367589
static: 0.004202533967367589
steel: 0.004202533967367589
steven: 0.004202533967367589
stick: 0.004202533967367589
stiffnessanddampingofapolybutadieneelastomerfilledwith3: 0.004202533967367589
stillmorerecently: 0.004202533967367589
stoffelm: 0.004202533967367589
stor: 0.004202533967367589
storageapplications: 0.004202533967367589
storagelaminate: 0.004202533967367589
storagestructuralcomposites: 0.004202533967367589
stored: 0.004202533967367589
strengthmultifunctionalcompositesforbiologicalimplants: 0.004202533967367589
strengthofunidirectionalglass: 0.004202533967367589
strengthwillstarttodropduetoparticleagglomeration: 0.004202533967367589
stressterms: 0.004202533967367589
strike: 0.004202533967367589
struct2007: 0.004202533967367589
struct2008: 0.004202533967367589
structmater: 0.004202533967367589
structuralactuation: 0.004202533967367589
structuralandstructuralfunctions: 0.004202533967367589
structuralbattery: 0.004202533967367589
structuralbatteryinwhichthepolymercathodeinaconventional: 0.004202533967367589
structuraldynamicsand: 0.004202533967367589
structuraldynmaterconf: 0.004202533967367589
structuralfibersconsistingofconductivestructuralfiberssuchas: 0.004202533967367589
structuralfunctionsinclude: 0.004202533967367589
structuralfunctionslike: 0.004202533967367589
structuralfunctionsofadvancedmaterials: 0.004202533967367589
structuralfunctionssince2000areemphasized: 0.004202533967367589
structuralhealthmonitoringofcompositestructure: 0.004202533967367589
structuralhealthmonitoringsensornetworks: 0.004202533967367589
structuralhealthmonitoringwithspecialemphasisoncompositematerials: 0.004202533967367589
structurallyintegratedbatteries: 0.004202533967367589
structurallyintegratedbatteriesforenergystorageareanother: 0.004202533967367589
structurallyintegratedelectroniccomponents: 0.004202533967367589
structurallyintegratedx: 0.004202533967367589
structuralmechanics: 0.004202533967367589
structuralpolymerlithium: 0.004202533967367589
structuralpropertiesofnanocompositesandhybridmul: 0.004202533967367589
structuredcompositescanproduceand: 0.004202533967367589
structuresduetoitsimportanceinthedevelopmentofmultifunc: 0.004202533967367589
structuresinthelastfewyears: 0.004202533967367589
structuresisnotclear: 0.004202533967367589
structurestechnologydemonstration: 0.004202533967367589
structuresubsystemweight: 0.004202533967367589

structureswhichhaveintegralnon: 0.004202533967367589
structuretoreconfigure: 0.004202533967367589
stuckygd: 0.004202533967367589
studied: 0.004202533967367589
study: 0.004202533967367589
su: 0.004202533967367589
sub: 0.004202533967367589
subjected: 0.004202533967367589
suboptimal: 0.004202533967367589
subsequent: 0.004202533967367589
substrate: 0.004202533967367589
suchasmorphingaircraftwings: 0.004202533967367589
suchaswirelesssensorsforstructuralhealthmonitoring: 0.004202533967367589
suchlayerscanbeintegratedintocompositestructuresfabricated: 0.004202533967367589
suhetal: 0.004202533967367589
suhk: 0.004202533967367589
suhwh: 0.004202533967367589
suhy: 0.004202533967367589
suitable: 0.004202533967367589
sulationsuchasnanoporoussilicacapsules: 0.004202533967367589
sules: 0.004202533967367589
sultsinlongitudinaldeformationofthefiber: 0.004202533967367589
sundararaju: 0.004202533967367589
supply: 0.004202533967367589
suredusingaspectrophotometer: 0.004202533967367589
surfaceareaofsphericalparticle: 0.004202533967367589
surfacesofmicron: 0.004202533967367589
surveyedrecentresearch: 0.004202533967367589
sustainability: 0.004202533967367589
swmt: 0.004202533967367589
swnt: 0.004202533967367589
swnts: 0.004202533967367589
swntsinepoxyresultedina125: 0.004202533967367589
swntsinimprovingdampingofepoxy: 0.004202533967367589
sys: 0.004202533967367589
syst: 0.004202533967367589
t300: 0.004202533967367589
tadigadapa: 0.004202533967367589
tailoring: 0.004202533967367589
taining: 0.004202533967367589
tajiri: 0.004202533967367589
takemurak: 0.004202533967367589
taken: 0.004202533967367589
takeyah: 0.004202533967367589
tance: 0.004202533967367589
tang: 0.004202533967367589
tangl: 0.004202533967367589
tanwk: 0.004202533967367589
taylor: 0.004202533967367589
taylorac: 0.004202533967367589
tdcb: 0.004202533967367589
technical: 0.004202533967367589
technol1999: 0.004202533967367589

technol2004: 0.004202533967367589
technol2006: 0.004202533967367589
technol2009: 0.004202533967367589
tehpl: 0.004202533967367589
telemedicine: 0.004202533967367589
telfeyan: 0.004202533967367589
temswork: 0.004202533967367589
tensilemodulusandafactorof2: 0.004202533967367589
tensilestrength: 0.004202533967367589
tensilestrengthandfracturetoughnessofepoxy: 0.004202533967367589
teohsh: 0.004202533967367589
terephthalate: 0.004202533967367589
terized: 0.004202533967367589
terpolymermatrixcompositescontainingsphericalaluminaparti: 0.004202533967367589
thambin: 0.004202533967367589
thana: 0.004202533967367589
thanisincreasingthebatteryenergy: 0.004202533967367589
thatfrac: 0.004202533967367589
thatofthebaselinecarbonfibers: 0.004202533967367589
thattheelectricalconductivityandtheelasticmodulusofthedif: 0.004202533967367589
thatthelayer: 0.004202533967367589
thearticleconcludeswithadiscussionofrecentapplicationsofmultifunctionalmaterialsandstructures: 0.004202533967367589
theauthorgratefullyacknowledgesthefinancialsupportfrom: 0.004202533967367589
theauthorisverygratefulfortheelec: 0.004202533967367589
theba: 0.004202533967367589
thebatteryshouldbecomepartof: 0.004202533967367589
thecapabilityofsimultaneouscontrolofstiffnessanddamping: 0.004202533967367589
thecntsarestraight: 0.004202533967367589
thecompositebyafactorofthreewhilecausingonlya5: 0.004202533967367589
thecomposites: 0.004202533967367589
thecompositescontainingpaniwireshada: 0.004202533967367589
thecompositeskinofafighteraircraft: 0.004202533967367589
theconcentration: 0.004202533967367589
thedevelopmentofanall: 0.004202533967367589
thedevelopmentofpolymersfromrenewableresourceshavebeen: 0.004202533967367589
thedifference: 0.004202533967367589
theeffectofrubbermicro: 0.004202533967367589
theelectricalconductivityofcompositeswithwavynanotubes: 0.004202533967367589
theenergyconversiondevicebeveryflexible: 0.004202533967367589
thefiber: 0.004202533967367589
thefieldofstructuralhealthmonitoring: 0.004202533967367589
theflexuralstrength: 0.004202533967367589
thehealing: 0.004202533967367589
theimpactresistance: 0.004202533967367589
theimportanceofwavinesswasconfirmed: 0.004202533967367589
theincorpora: 0.004202533967367589
theincreasinguseofcompositematerialshasbeendriveninpart: 0.004202533967367589
theinfluenceofsingle: 0.004202533967367589
theircomposites: 0.004202533967367589
theircompositesassensorsandactuators: 0.004202533967367589
thelargea: 0.004202533967367589
thelithiumenergycellsdidnotsig: 0.004202533967367589

theload: 0.004202533967367589
themanufactureofcompositestructureswithabuilt: 0.004202533967367589
thematrixofthemfnpscouldbeametaloxidenetwork: 0.004202533967367589
themechanical: 0.004202533967367589
themechanicalpropertieswerepoor: 0.004202533967367589
themostcommonmodeofenergyharvestinginvolvestheuse: 0.004202533967367589
themostwidelyusedcompositeshavepolymermatrixmaterials: 0.004202533967367589
themostwidelyusedformsofpiezoelectricmaterialsarewa: 0.004202533967367589
themotionand: 0.004202533967367589
themultifunctionallaminate: 0.004202533967367589
themultifunctionalmaterialorsystemforspecificapplications: 0.004202533967367589
thenconductedsinglefiberfragmentationtestsofthe: 0.004202533967367589
thenumberofpublicationsdealingwithvariousaspectsofthe: 0.004202533967367589
theor: 0.004202533967367589
theorganicliquidelectrolytewasreplacedwithasolid: 0.004202533967367589
theory: 0.004202533967367589
thepenaltyofaddedweight: 0.004202533967367589
thepfclaminatewasbuiltupfrompfclam: 0.004202533967367589
thepolymeradhesivelayerswereenhancedwith2wt: 0.004202533967367589
thepolymerdensitynearthepolymer: 0.004202533967367589
thepolymermustbeeitheranintrinsicallyconductingpolymer: 0.004202533967367589
thepoweroutputfromarandomlyvibratingpiezoelectricmaterial: 0.004202533967367589
thepresenceofthenanoparti: 0.004202533967367589
thereareotherissuessuchashygrother: 0.004202533967367589
therehasbeenin: 0.004202533967367589
thereisaneed: 0.004202533967367589
theresultingload: 0.004202533967367589
thermaldegradationofgreenandupgraded: 0.004202533967367589
thermalpropertiesandpercolation: 0.004202533967367589
thermodynamics: 0.004202533967367589
thermomechanical: 0.004202533967367589
thermoplast: 0.004202533967367589
thermosetmatrix: 0.004202533967367589
thermosetting: 0.004202533967367589
thesame: 0.004202533967367589
thesamematerialordevicecanbe: 0.004202533967367589
thesearemajorconcernsaboutconventionalcom: 0.004202533967367589
theseareveryactiveresearchareas: 0.004202533967367589
thesestructures: 0.004202533967367589
theso: 0.004202533967367589
thestate: 0.004202533967367589
thestrengthandmodulusvaluesfornaturalfibersarewell: 0.004202533967367589
thestructuraladvantagesofnanocomposites: 0.004202533967367589
thetensilemodulusofthebatterywasonlyabout3gpa: 0.004202533967367589
thethermalconductivityandtheelec: 0.004202533967367589
thethermalen: 0.004202533967367589
thethermalmanagementcapabilitiesofaheatpipewithstructural: 0.004202533967367589
thetraditional: 0.004202533967367589
theuseofcar: 0.004202533967367589
theuseofnanoreinforcementsinpolymercompositeshaspro: 0.004202533967367589
theuseofotherhighaspectratioelectrically: 0.004202533967367589
theuseofthealignedcntforeststoimproveinterlaminarstrength: 0.004202533967367589
theusualsolutiontoemiistoprotectthecircuitwithanemi: 0.004202533967367589

thevastmajorityofthesurveyedarticlesdealwithpolymercom: 0.004202533967367589
theyalsoreportedontheuseofthepiezoelectricoutputtocharge: 0.004202533967367589
theyoung: 0.004202533967367589
thick: 0.004202533967367589
thicker: 0.004202533967367589
thicknessthermal: 0.004202533967367589
thill: 0.004202533967367589
thillc: 0.004202533967367589
thisarticleisanattempttoidentifythetopicsthataremostrelevantto: 0.004202533967367589
thisequationshowsthatintegratingthebatterywiththestruc: 0.004202533967367589
thishypothe: 0.004202533967367589
thisisparticularlytrueforanalyticalmodeling: 0.004202533967367589
thisisparticularlytrueforelectroac: 0.004202533967367589
thismaylead: 0.004202533967367589
thisreview: 0.004202533967367589
thomas: 0.004202533967367589
thomasjp: 0.004202533967367589
throughout: 0.004202533967367589
thus: 0.004202533967367589
thus2798: 0.004202533967367589
thusenhancingtheir: 0.004202533967367589
ti: 0.004202533967367589
ticledispersionandreducedsilica: 0.004202533967367589
ticles: 0.004202533967367589
tie: 0.004202533967367589
tifunctionalcompositelaminate: 0.004202533967367589
tifunctionalefficiencyforsystemlevelweightsavingsshownbythe: 0.004202533967367589
tifunctionalmaterialsandstructureswhicharetypicallybasedon: 0.004202533967367589
tifunctionalnanoparticlesystems: 0.004202533967367589
tiguestrength: 0.004202533967367589
tio: 0.004202533967367589
tional: 0.004202533967367589
tionalstructures: 0.004202533967367589
tionsinthisareacomesaneedforacomprehensivereviewarticle: 0.004202533967367589
tionthreshold: 0.004202533967367589
tiscalecomposites: 0.004202533967367589
titanate: 0.004202533967367589
tivemoleculessuchasdrugsorantibodies: 0.004202533967367589
tiveness: 0.004202533967367589
tiveshapememorypolymercompositescontainingconductivefill: 0.004202533967367589
tn: 0.004202533967367589
to15nm: 0.004202533967367589
toahollowaluminumplatewhichhasaseriesofsmallcompart: 0.004202533967367589
tocoastandaroundtheworld: 0.004202533967367589
toddmd: 0.004202533967367589
todevelopmultifunctionalaircraftwingswhichcanchangeshape: 0.004202533967367589
todevelopsensorsthatarecapableofdetectingmultiplephenom: 0.004202533967367589
todevelopthetechnologytoembedabroadbandrfantennainto: 0.004202533967367589
todorokia: 0.004202533967367589
together: 0.004202533967367589
toincreasetheviscosityofthemixturebeyondthedesirablepro: 0.004202533967367589
tong: 0.004202533967367589
tooheyks: 0.004202533967367589

tooptimizebothproperties: 0.004202533967367589
tooquicklyforpracticalenergystorageandthatbatteriesprovided: 0.004202533967367589
topic: 0.004202533967367589
toprocessingissues: 0.004202533967367589
tor: 0.004202533967367589
toughenedepoxy: 0.004202533967367589
toughening: 0.004202533967367589
tougheningwith: 0.004202533967367589
toughnessofaerospacegradecarbon: 0.004202533967367589
toxicity: 0.004202533967367589
trabiamb: 0.004202533967367589
traditionallypoorpropertiescanbesignificantlyimprovedby: 0.004202533967367589
trailingedgeforflightcontrolofablendedwingbodyairliner: 0.004202533967367589
transducer: 0.004202533967367589
transfer: 0.004202533967367589
transmission: 0.004202533967367589
transparent: 0.004202533967367589
transparentpanels: 0.004202533967367589
transverse: 0.004202533967367589
traskr: 0.004202533967367589
tratedinfig: 0.004202533967367589
tration: 0.004202533967367589
trationinthepolymerthatcharacterizestheinsulator: 0.004202533967367589
treat: 0.004202533967367589
treatment: 0.004202533967367589
tressler: 0.004202533967367589
trim: 0.004202533967367589
trivedi: 0.004202533967367589
trix: 0.004202533967367589
troiler: 0.004202533967367589
tronic: 0.004202533967367589
tube: 0.004202533967367589
turalfibercompositesaresuitableforvibrationcontrol: 0.004202533967367589
ture: 0.004202533967367589
tureloadandcorrespondingfracturetoughnessfortheself: 0.004202533967367589
tureoroneoftheothersubsystemscanleadtoanincreasedflight: 0.004202533967367589
tureshasbeendrivenbycurrentandpotentialaerospaceapplica: 0.004202533967367589
tureshavebeenreviewedbyanandhyeon: 0.004202533967367589
turesisdrivenbytheneedforthedevelopmentofnewmaterials: 0.004202533967367589
tuss: 0.004202533967367589
two: 0.004202533967367589
typ: 0.004202533967367589
typeofpolyelectrolytedeterminesthesensitivitytoph: 0.004202533967367589
typically: 0.004202533967367589
typicallybreaksupcntsintoshorterlengths: 0.004202533967367589
typicallyhave: 0.004202533967367589
t¼20log: 0.004202533967367589
uav: 0.004202533967367589
uavisgivenby: 0.004202533967367589
uldrichf: 0.004202533967367589
ultra: 0.004202533967367589
uncracked: 0.004202533967367589
unitedstates: 0.004202533967367589

universityofnevada: 0.004202533967367589
unmanned: 0.004202533967367589
unprecedented: 0.004202533967367589
unr: 0.004202533967367589
urban: 0.004202533967367589
usable: 0.004202533967367589
usebysoldierswasdevelopedbygranstrometal: 0.004202533967367589
usedaconventionalcurekineticsmodelandelectricalresis: 0.004202533967367589
usedforbothfunctions: 0.004202533967367589
usedthelblmethodtofabricatea: 0.004202533967367589
useinsensorsandactuators: 0.004202533967367589
useofalignedcntforeststostrengtheninterlaminarregionincompositelaminates: 0.004202533967367589
useofani60tishape: 0.004202533967367589
useofani60tishapememory: 0.004202533967367589
useofthree: 0.004202533967367589
usingpiezoelectricmaterials: 0.004202533967367589
utilized: 0.004202533967367589
vacuum: 0.004202533967367589
vaidyaetal: 0.004202533967367589
validatednumericalanalysis: 0.004202533967367589
validation: 0.004202533967367589
value: 0.004202533967367589
varadanvk: 0.004202533967367589
variableswhichgovernthestiffnessanddampingofmresarethe: 0.004202533967367589
variousdegreeofdegradability: 0.004202533967367589
vartm: 0.004202533967367589
vch: 0.004202533967367589
vchverlaggmbh: 0.004202533967367589
veedu: 0.004202533967367589
veeduetal: 0.004202533967367589
velopprocesseswhichpreservethehighaspectratiosofcnts: 0.004202533967367589
ventional: 0.004202533967367589
verlag: 0.004202533967367589
versityofnevada: 0.004202533967367589
vertical: 0.004202533967367589
vertically: 0.004202533967367589
veryrecentlyreviewedbytadigadapaandmateti: 0.004202533967367589
vforamicron: 0.004202533967367589
viathelatentheatofthephasechangematerial: 0.004202533967367589
vibrationsofcarbonnanotubesandtheir: 0.004202533967367589
vide: 0.004202533967367589
view: 0.004202533967367589
viewarticlebyratnaandkarger: 0.004202533967367589
viewedarticlesdealingwithicpsforemi: 0.004202533967367589
viewedrelevantresearchonelectricalpercolationincarbonnano: 0.004202533967367589
vijayan: 0.004202533967367589
vinyl: 0.004202533967367589
vinylesternanocompositewhilepreservingthehigh: 0.004202533967367589
virgin: 0.004202533967367589
vitro: 0.004202533967367589
vlasveld: 0.004202533967367589
vlasvelddpn: 0.004202533967367589
vol: 0.004202533967367589

volkovd: 0.004202533967367589
volumeofsphericalparticle: 0.004202533967367589
volvestheuseofprintedcircuittechnologytoproduceathinflex: 0.004202533967367589
vp: 0.004202533967367589
vratiosandresult: 0.004202533967367589
wadleyhng: 0.004202533967367589
wafer: 0.004202533967367589
wagimananr: 0.004202533967367589
wangb: 0.004202533967367589
wangd: 0.004202533967367589
wangdz: 0.004202533967367589
wangkw: 0.004202533967367589
wanglf: 0.004202533967367589
wardslightweightcompositematerialsinrecentyears: 0.004202533967367589
washypothesizedthatfrictionalslidingattheswnt: 0.004202533967367589
wasp: 0.004202533967367589
wasreportedlaterin: 0.004202533967367589
wasterequiresspecialconsiderationduetopotentialtoxicity: 0.004202533967367589
wasthereasonfortheenhancedenergydissipation: 0.004202533967367589
wavy: 0.004202533967367589
way: 0.004202533967367589
weak: 0.004202533967367589
wearable: 0.004202533967367589
wearablefabricsforhumanbiomonitoringmadebycarbonnanotubecoating: 0.004202533967367589
weaverp: 0.004202533967367589
wei: 0.004202533967367589
weibq: 0.004202533967367589
weinachtp: 0.004202533967367589
weissra: 0.004202533967367589
wennhage: 0.004202533967367589
weny: 0.004202533967367589
wereableto: 0.004202533967367589
wereappar: 0.004202533967367589
werefound: 0.004202533967367589
werethefirsttoreportthat: 0.004202533967367589
whendamagecausescracksinthe: 0.004202533967367589
whenthecompositewasmechanicallyloadedtoashighas50: 0.004202533967367589
whenusedasmatrixmaterialsinmultifunctionalfibercomposite: 0.004202533967367589
whereasanexam: 0.004202533967367589
whereasstructuralcompositeshavegoodstiffnessbutpoorenergy: 0.004202533967367589
whicharetooheavy: 0.004202533967367589
whicharetypicallypoorconductors: 0.004202533967367589
whichinturn: 0.004202533967367589
whichinvolvessequentialdepo: 0.004202533967367589
whichisembeddedwithinaconventionalcom: 0.004202533967367589
whichisthecntconcen: 0.004202533967367589
whichmakesitdifficult: 0.004202533967367589
whichr: 0.004202533967367589
whichwasheldinhongkong: 0.004202533967367589
whilegibsonetal: 0.004202533967367589
whileicpssuchaspolyaniline: 0.004202533967367589
whileinthesensing: 0.004202533967367589
whilepointingoutthattheareaisstillinitsinfancyandthatsolu: 0.004202533967367589

whiletheemishieldingpropertiesofcarbonnanofiber: 0.004202533967367589
whiletransparencywassomewhatreducedbutacceptable: 0.004202533967367589
whilewangandjing: 0.004202533967367589
whileyeetal: 0.004202533967367589
whodevelopeda: 0.004202533967367589
whomeasuredmodulusandstrengthofvinyles: 0.004202533967367589
whore: 0.004202533967367589
whoused: 0.004202533967367589
whousedacoppernano: 0.004202533967367589
wich: 0.004202533967367589
wick: 0.004202533967367589
wideelectrodeunderstaticloadingforseveralelectrodethicknesses: 0.004202533967367589
width: 0.004202533967367589
wiley: 0.004202533967367589
williams: 0.004202533967367589
williamsg: 0.004202533967367589
willk: 0.004202533967367589
windleah: 0.004202533967367589
wing: 0.004202533967367589
wingplanformarea: 0.004202533967367589
wire: 0.004202533967367589
withadistributedhybridpzt: 0.004202533967367589
withcon: 0.004202533967367589
withdecreasingparticle: 0.004202533967367589
withempha: 0.004202533967367589
withmicrovascularnetworks: 0.004202533967367589
without: 0.004202533967367589
withoutwhichthisarticlewouldnothave: 0.004202533967367589
withparticlesizesrangingfrom0: 0.004202533967367589
withpolyelectrolytes: 0.004202533967367589
withthegeneralareaofstructuralhealthmonitoring: 0.004202533967367589
withthemovermanyyears: 0.004202533967367589
wong: 0.004202533967367589
wordenk: 0.004202533967367589
wouldbeacompositestructurethathashighstrength: 0.004202533967367589
wouldbeaload: 0.004202533967367589
wu: 0.004202533967367589
wudy: 0.004202533967367589
wunsch: 0.004202533967367589
wuz: 0.004202533967367589
www: 0.004202533967367589
xue: 0.004202533967367589
xug: 0.004202533967367589
xw: 0.004202533967367589
ya: 0.004202533967367589
yam: 0.004202533967367589
yamamoton: 0.004202533967367589
yanetal: 0.004202533967367589
yangy: 0.004202533967367589
year: 0.004202533967367589
yeohck: 0.004202533967367589
yimw: 0.004202533967367589
yin: 0.004202533967367589

yint: 0.004202533967367589
yj: 0.004202533967367589
yul: 0.004202533967367589
zafeiropoulosn: 0.004202533967367589
zagrai: 0.004202533967367589
zengc: 0.004202533967367589
zhangc: 0.004202533967367589
zhangh: 0.004202533967367589
zhangl: 0.004202533967367589
zhangmq: 0.004202533967367589
zhangz: 0.004202533967367589
zhaoh: 0.004202533967367589
zhaojq: 0.004202533967367589
zhengm: 0.004202533967367589
zhoux: 0.004202533967367589
zhujw: 0.004202533967367589
ziaee: 0.004202533967367589
zoelectric: 0.004202533967367589
¼ðu: 0.004202533967367589
ð1þ: 0.004202533967367589
ð2þ: 0.004202533967367589
ð3þ: 0.004202533967367589
ð4þ: 0.004202533967367589
ð5þ: 0.004202533967367589
ð6þ: 0.004202533967367589
ðw: 0.004202533967367589
þ3: 0.004202533967367589
þa: 0.004202533967367589