Processed Text

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thematerialpropertyrequirementsforaerospacematerialsvarywith
theparticularcomponentunderconsideration materialsselectionforan
aircraftdesigndependonthedesignrequirementsofeachcomponent includingloadingconditions
manufacturability geometriclimits envi ronmentalaspects andmaintainability 21 2 1
thedesigncriteriaoftheairframematerials airframematerialsaredesignedtoprovidelong term 60000flight
hour supportforboththestaticweightofaircraftandadditionalload subjectedfromservice 1
thisconceptrequiresairframematerialsto posse acceptable density weight reduction appropriate
mechanicalpropertiesfortheintendeduse italsorequiresmaterialsto
providesuitabledamagetoleranceforthe purposeoflong termusein extreme temperature condition 30 370
cid 1 c moisture extreme fig 1 totalmaterialsusedinboeingseriesaircraft 1 3 humidity desert environment
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itisalsosubjectedtoadditionalloadsfrom thelandinggear theleadingedgeslats
andthetrailingedgeflapsduring taxiing take offs landing therefore wing upper surface
undercompressionduringtheflightandtensionduringthetaxing thelowersurfaceisundertheoppositeloads
thisrequiresthematerials forthewingtoprovidebothhightensilestrengthandhighcompressive strength 1
fuselage exposed condition high cabin pressure shear load requires material posse high tensile shear
strength al based alloy one widely used airframe material example 2024 al based alloy beenwidely
usedinfuselagesbecauseofitsmoderateyieldstrength 324mpa good fracture toughness 37mpam1 2 high
elongation rate 21 moreover theuseofpolymermatrixcomposites pmc suchascfrp
foraircraftstructureshassignificantlyincreasedinrecentyearsbecause oftheirhighstrength 3450
4830mpaforstandardmoduluscfrp elastic modulus 224 241gpa high temperature capability
withstandtemperaturesbetween290and345 cid 1 c 22 fig 2
typicalyieldstrengthandelongationofsomemetalalloys alalloys 2 2 thedesigncriteriaoftheaircraftengine
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mgalloysincludemg97zn1y2 az91 zk60 andwe43 5 ti
thrustimprovementandweightreductionforaircraftengineshave alloy include ti 5al5v5mo3cr ti 6 4 12 ti
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steelsincludeaisi316l aisi321 materialsarerequiredtopossesslowdensitiesforweightreduction aisi304
andaisi347 19 good mechanical property high temperature corrosive envi ronment aircraft turbine
engine consist cold section fan mechanicalpropertiesthanconventionalstainlesssteelathightemper
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althoughaerospacematerialshavemadegreatadvancements material ti basedalloys al basedalloys
andpolymercompositesare stillfacemajorchallenges theapplicationsofaerospacematerialsare
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600 cid 1 c high enough meet increasing demand moreover frequentlyusedmaterialforthispartisti
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thewidelyusedmaterialsforthisappli wellastoprovideapictureofcurrentchallengesandfuturetrends cation
ni based superalloys ni 14 5zr 3 2mo excellentheat resistancestrength 780mpaat950 cid 1 c 24 23x
zhangetal progressinaerospacesciences97 2018 22 34 3 recentadvancesinaircraftmaterials alloy
zinchasthelargestsolubility 31 6wt inaluminumthanany otherelement
andtheincreaseofzncontentcanimprovethestrength 3 1 al basedalloys 27
mgandcuoftenusedincombinationwithzntoformmgzn2phase al2cumg phase alcumgzn phase aluminum
resulting al based alloy primary material aircraft remarkablesolid solutestrengthening
themaximumtensilestrengthof structure increased use composite al based alloy still al
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remainasimportantairframestructurematerialsbecauseoftheirseveral based alloy also contain copper
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basedalloysaremainlyalloyedwithcopperandthey modification zn mg cu ratio improve damage
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zr mn reportedto improve alloy andal libasedalloysareshownintable1 oneofthetypical
mechanicalpropertiesofal znbasedalloys 32 33 theadditionofzr example 2000 series alloy 2024 alloy
widely decrease average grain size approximately 20 form rosette like
studiedasaircraftfuselagematerialwherethedamagetoleranceisfirst
microstructureandintroducesproperdistributionofthesecondphases consideration however
therelativelowyieldstrengthlimitstheuseof 32 mncancombinewithfetoformsecondaryphaseinal znbased
2024 alloy high stress region addition intermetallic phase alloy increase fracture toughness al zn based
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higher fracture toughness hardnessvalueofal cu mgbasedalloyincreasewiththecontentofsn 52mpam1 2
andfinergrainsizethanconventional7075alloybecause upto0 06wt
butthendecreasewiththefurtherincreaseofsncontent ofthelowercontentofironandsilicon total0 22wt
of7475alloy 25 furtherimprovementofmechanicalpropertiesofal cubasedal than7075alloy total0 9wt
loyscanbeachievedbycontrollingtheimpurities suchasironandsil icon example 2224 t39 al cu based alloy
higher tensile 3 1 3 al libasedalloys strength uts¼476mpa conventional 2024 al cu based alloy
themaximumsolubilityofliinalreachesupto14 atatempera uts¼428mpa becauseofthelowercontentsofiron
0 12wt tureof600 cid 1 c 34 themajoreffectofliinalistoreducethedensityof silicon 0 10wt than2024alloy 0
5wt forbothimpurities 1 al basedalloys when1wt liisadded thedensityofal basedalloyis reducedby3

whileyoung smodulusincreasesby6 35 therefore 3 1 2 7000seriesal znbasedalloys al li based alloy lightest al based alloy 36 addition 7000seriesal basedalloysaremainlyalloyedwithzincandtheyare additionofcuisoftenusedincombinationwithlitoformal2culiphase heat treatable highest strength series al based toimprovethemechanicalpropertiesofalalloys 37 consequently al li based alloy posse low density high specific mechanical property 2000 7000 series alloy example use table1 2060 t8al libasedalloyforfuselageskinandupperwingskinappli mechanicalpropertiesofsomerepresentativealuminumalloys 1 26 cation save 7 weight 14 weight respectively compared alloy ut yieldstrength fracturetoughness kic elongation withthatofconventional2524alloyand2014alloy respectively 1 mpa mpa mpam0 5 however highcontent 1 8wt ofliinaluminumhasbeenprovedto 2025 428 324 37 21 causeananisotropyprobleminal basedalloys 1 38 forexample t351 yieldstrengthofaa2198al libasedalloyinthelongitudedirectionis 2026 496 365 na 11 90mpahigherthanthatinthetransversedirection 39 theanisotropy t3511 2224 t39 476 345 53 10 ofmechanicalpropertiesresultsfromthecrystallographictexture grain 2324 t39 475 370 38 5 44 0 8 shape size precipitate aging process addition 2524 t3 434 306 40 tl 24 earlier al li based alloy posse low toughness poor corrosion 7150x 808 9 776 5 12 7 14 1 resistance recent study focus composition optimization t6 7075 t6 656 590 25 5 cid 3 4 6 11 cometheseshortcomings theanisotropyproblemofal libasedalloys 7475 552 496 42 9 12 canbereducedbyintroducingrecrystallizationthroughoptimizationof t651 composite thermal mechanical processing 40 example 2050 t84 540 500 43 na 2198al libasedalloycontaining40wt mncanberecrystallizedby 2090 t83 531 483 43 9 3 40 in3minundertheconditionof535 cid 1 c 41 inaddition theyield 2098 t82 503 476 na 6 2099 t83 543 520 30 lt 7 6 strengthofanal li cu mgalloyattherollingdirectionis80mpahigher 2199 t8 400 345 53 10 thanitisat60 cid 1 fromtherollingdirectionintheconditionofunder aged 8090 500 455 33 lt 12 however yield strength alloy isotropy aged t851 condition 42 addition low fracture toughness al li based 24x zhangetal progressinaerospacesciences97 2018 22 34 alloyscanbeimprovedbyreducingtheinsolublesecond phaseparticles 3 3 ti basedalloy suchasal7cu2fe 4 forexample therecentadvanced2199al libased alloyhas20mpam1 2higherfracturetoughnessthanearlier8090al li use ti based alloy increased recent year based alloy obtained optimization composition showninfig 3 theoperatingemptyweight oew whichistheweight thermal mechanical processing precipitate microstructure control ofalloperatoritems equipmentrequiredforflight andallfluidneces 1 sary operation witnessed increasing use ti based alloy from1 to19 ti basedalloyshavebeenusedforbothstructureand 3 2 mg basedalloys engineapplications suchasaircraftspring helicopterrotorsystemsand enginecompressorparts seefig 4 theattractivenessofti basedalloys mgisconsideredthelighteststructuralmetal 43 andcandecrease mainly due high specific strength excellent corrosion resis weight structure approximately 33 compared tance well high temperature performance generally ti based al samevolumeofaluminumusedandby77 whencomparedtothesame loys divided three category based type crystal volume steel used 44 addition low density abundance structure alpha titanium alloy beta titanium alloy alpha beta castability recyclability also contribute attractiveness alloy therecentresearchesonthedevelopmentofti basedalloysfor mg basedalloys 45 commercialmg basedalloyscanbedividedinto aircraftapplicationsarereviewed two category wrought mg basedalloys casting mg basedalloys generally wroughtmg basedalloyshavebettertensilepropertiesthan 3 3 1 alphatitaniumalloys castingmg basedalloysbuthaveahigherasymmetryofyieldbehavior alphatitaniumalloyscanbedividedintoalphaandnear alphaal 46 admittedly theuseofmg basedalloysbythetopaircraftmanu loys whichentirelyormostlyconsistofαphasewithneutralalloyele facturers airbus boeing lockheed martin limited mentsorαstabilizers 23 ingeneral alphatitaniumalloyhasalower mg based alloy az91 ze41 we43a ze41 used heli density highercreepresistanceandbettercorrosionresistancethanbeta copterindustrytomakecastgearboxtransmissionssuchasforsikorsky titaniumalloy 23 becauseof theseproperties alpha titanium alloy helicopter 92 uh60 helicopter 6 43 47 drawback cp ti ti 3al 2 5v ti 5 2 5 ti 8 1 1 ti 6 2 4 2 imi829 mg based alloy aerospace industry insufficient imi834 timetal ii00 used manufacture compressor chanical property poor corrosion resistance stress corrosion discbladesinaircraftengines 23 56 despitetheattractivenessofal crackingissue phastitaniumalloy someresearch 14 57 hasshownthatalphaphase toimprovethepoorcorrosionresistanceandinsufficientmechanical greatly limit high temperature capability titanium alloy property element al zn zr rare earth ele fortunately thealphastabilizingadditionsenablethesealloystoservein mentssuchasyarebeingemployedtoimprovethepropertiesofmg aircraftjetenginesinwhichthetemperaturecanreachupto600 cid 1 c al based alloy refining modifying microstructure sn zr andsihavebeeninvestigatedtoimprovetheheat resistanceof widelystudiedisalelement thelow densityalelementhasamaximum alphaornearalphatitaniumalloys alisthemostwidelyusedtoimprove solubility12 7wt inmgandcanmergeintomgtoformthephasesof strength alpha titanium alloy high temperature 58 γ mg17al12andα mg whichisbeneficialtosolid solutionstrengthening experiment conducted jiang et al 59 showed tensile mg al based alloy moderate mechanical property strengthofati 25zrtitaniumalloyincreasedfrom931mpato1319mpa corrosionresistance whichcanbesignificantlyimprovedbyincreasing withtheincreasingofalcontentfrom0 to15 theyieldstrengthwas alcontent 5 48 inadditiontoal znelementcanimprovethestrength increased 47 raising addition al 15 however andductilityofmg albasedalloysatroomtemperature 5 thesolu elongation decreased 14 79 5 55 increase al bilityofznintomgis6 2wt andcanformα mgandγ mgznphases content thestrengthefficiencyofalinti zrbasedalloysismainlydue whicharebeneficialtoimprovethestrengthsofmg basedalloy withthe tothesizeandmodulusmisfitsbetweenalandzr increaseoftheznelementfrom1wt to5wt theyieldstrengthof mg znbasedalloysrises moreover theutsincreasesto216 8mpaand 3 3 2 betatitaniumalloys elongationincreasesto15 8 whenthecontentofznreachedupto4wt betatitaniumalloysareentirelyormostlyconsistofβphasewithβ andthendecreaseswithadditionalzncontentadded 5 49 stabilizer beta near beta alloy higher tensile fatigue ever thecorrosionresistanceofmg znbasedalloydecreaseswiththe strength alpha titanium alloy easier fabrication rising zn content mainly increasing volume semiproducts 60 thehighstrengthofbetatitaniumalloysisresulted fractionsofthesecondphasemgxzny 50 inmg znbasedalloys zrand yareoftenusedincombinationwithzntoimprovemechanicalprop erties zrisconsideredthebestrefinerformg basedalloyswithoutal elementduetothereactionofzrandal 51 thebenefitofzrinmg zn basedalloyistorefinethegrainsizeanddispersethemgzn2phase 52 hommaetal 52 reportedthattheutsandysofanal znbasedalloy increased 275mpa 148mpa 357mpa 310mpa respectively whenthecontentofzrincreasedfrom0wt to0 84wt addition zr rare earth element also improve chanicalpropertiesofmg znbasedalloys themg97zn1y2alloyhasthe highest strength ys¼610mpa among mg based alloy caused adding rapid powder metallurgy processing 5 however strengthsofmg znbasedalloyscanbereducedwheny elementexceedsthecriticalamount forexample xuetal reportedthat theutsofamg zn zralloywasincreasedto230mpabyadding1 08wt amountofy andthendecreasedto180mpawhentheamountofy wasincreasedto3 08wt similarsituationsoccurredonys inaddi tion xu co worker studied effect elongation rate mg zn based alloy result showed elongation decreasedto3 6 whenthecontentofyincreasedto1 08wt andthen increasedslightlywithadditionalycontentadded 53 fig 3 titaniumusageinsomeaircrafts 54 25x zhangetal progressinaerospacesciences97 2018 22 34 fig 4 component made ti basedalloy landinggearbeamforboe ing747 b bulkheadforafighteraircraft c wing box b1 b bomber aircraft springsusedinboeingaircraft e acasting usedinamilitarytransportaircraft 55 fromthebeta stabilizer suchasv mo nb andcr thesealloyingatoms 70 someelementssuchaszrhasbeenreportedtoimprovehardness canreducethebindingenergyofthebeta tiatomiccluster resultingin strength ti 6al 4v alloy due effect solid solution strongerbondsbetweenalloyingatomsandtitaniumatomsthanthoseof strengthening inwhichtheαphaseplateletsarereplacedfineacicularα0 ti tiatoms andthebindingenergydecreaseswiththeincreasingcon phase resultingcloselamellarspacingstohinderdislocationmovement tent alloying element 61 addition occurrence ω phase 71 themicrohardnessofti 6al 4valloycanbeincreasedto420hv duringcoldrollingalsohasasignificanteffectonmechanicalproperties byadding20wt zr inaddition thetensilestrengthcanbeincreased beta titanium alloy 62 example ti 3al 8v 6cr 4mo 4zr from996mpato1317mpabyincreasingzrcontentfrom0wt to20wt alloyhasaminimumutsat1240mpa andti 15v 3cr 3al 3snhasa however theelongationratiodroppedto8 08 minimumutsat1034mpa consequently thesetwoalloysarewidely usedinhigh stressregionsuchasaircraftlandinggearandaircraftspring 3 4

compositematerials application 60 addition ti 3al 8v 6cr 4mo 4zr ti 15v 3cr 3al 3snalloys
fourbetatitaniumalloysareinsteadypro theuseofcompositematerialshassignificantlyincreasedandcom
duction ti 10v 2fe 3al ti 15mo 2 7nb 3al 0 2si positesnowconstitutemorethan25 oftheairbusa380and50
ofthe ti 5al5v5mo3cr0 5fe andti 35v 35cr 63 however betatitanium boeing787aircrafts seefig 5
compositematerialsshowagreatpo alloysarereportedtopossesslowtensileductility 55 fortunately
tentialinnotonlystructuralapplicationsbutalsosomeengineparts shortcoming overcome optimization
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5al3zr4mo4v4cr uts¼1370mpa elongation¼17 containing tance metal recent research development
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theincreasedductilityinmainlyduetothegrowthofsphericity 3 4 1 ceramicmatrixcompositematerial
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betatitaniumalloys icon nitride si3n4 alumina al2o3 zirconia aluminum titanate
becauseoftheexcellentcombinationsofstrength fracturetoughness al2tio5 aluminum nitride aln matrix
composite widelystudiedinrecentyearsbecauseoftheirattractiveproperties andductility thealpha
betaalloyisthemostwidelyusedti basedalloy high temperature stability withstand operating temperature
w ush ei dch aa ncc doun stt u df io er da7 a0 lp hash ba er te aof lh loe yu ri etan tiu 6am l 4r vk et tt ih
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corrosionresistance andgoodversatility 9 74 ceramicmatrixcom ti 6al 2sn 2zr 2cr 2mo si 65 ati 425
positesarenormallyusedinhigh temperaturesectionsinaircraftsuchas ti 4al 2 5v 1 5fe 0 25o 66 tc21
exhaustnozzle carbonfiberreinforcedsiliconcarbidehasbeeninves ti 6a1 2zr 2sn 3mo 1cr 2nb 67
thesealloyshavebeenapplied tigatedasacandidateforaircraftbrakeswherethetemperaturecould aircraft
structure engine part including fuselage reachupto1200 cid 1 cunderemergencybrakeconditions 75
despitethe landinggear floorsupportstructure nacelle andcompressordiscs 23 merit mmcs reported
suffer poor fracture toughness among alloy widely used ti 6al 4v 76 toovercomethisshortcoming
variousworks 74 77 havefocused accounted half u titanium consumption 68 ti 6al 4v addition
nanomaterials carbon nanotube alloyhasayieldstrengthandanultimatetensilestrengthof1180mpa
graphenetoimprovethefracturetoughnessofceramicmatrixcompos
and1300mpaundersubmicrocrystalline smc condition respectively ites however ahmadetal 74
reportedtheeffectsofcarbonnanotubes 69 however ti 6al 4v alloy low hardness value 28 4 hrc cnts
onthefracturetoughnessofcmcareinconsistent ahmadet al 26x zhangetal
progressinaerospacesciences97 2018 22 34 fig 5 percentage total structural weight attrib uted
composite use composite airbus a380 thepercentageoftotalstructuralweightattrib uted composite b use
composite airbus a380 72 73 believethatgraphenenanoplatelets gnp areanefficientalternative based
mmc reinforced 30 sic similar density 60 higher
forcntsinceramiccompositebecauseofthesimilarmechanicalprop elastic modulus 15 higher tensile
strength 70 higher specific ertiesandbetterdispersibilitytocnts anexperimentbywalkeret al
modulusthan2219al basedalloys 79 recently somemetalsandal 76 demonstratedanincreaseof235
infracturetoughnessofasi3n4 loys werestudiedas matricessuchasaluminum magnesium tita
ceramiccompositebyadding1 5vol ofgraphene however thecon nium copper nickel 80 property matrix
tentofgrapheneplateletshouldbelimitedatcriticalvalue forexample shownintable2
somefiberssuchasceramicreinforcementandcon liuetal 77
reportedthefracturetoughnessofaluminaceramiccom
ventionalcarbonfiberwereinvestigatedfortheirpotentialtoimprove positeincreasedto4 49mpam1
2whengraphenecontentrosefrom0to property mmc however fiber meet 0 38vol dropped 3 53mpam1 2
content quirementsforfurtherimprovementofmechanicalpropertiesofmmc graphenereachedupto1 33vol
carbon nanotube cnts graphene nanosheets recently shown attractiveness demand fiber higher 3 4 2
metalmatrixcompositematerials strength lower coefficient thermal expansion better self lubricant
metalmatrixcomposites mmcs holdpromisefortheaerospacein ability andhigherdampingcapacity 81
theeffectsofcarbonnano dustrybecauseoftheirreinforcedhigheryieldstrength fracturetough
tubesonmmchavebeenstudiedbyliaoetal 81 82 theyreported ness lowthermalexpansion
andsuitablewearresistance 78 theal thatdifferentamountsofmulti wallednanotube mwnt havedifferent

27x zhangetal progressinaerospacesciences97 2018 22 34 table2 propertiesofsomemetalmatricesofcomposites 87 88 matrix densityg cm3 cte thermalconductivity yieldstrength ut young smodulus elongation 10 cid 4 6k cid 4 2 w mk mpa mpa gpa al2024 2 78 22 7 120 345 425 70 5 al6061 t6 2 71 23 2 160 193 227 69 10 albemet 2 1 13 9 240 282 338 199 10 ti6al4v 2 43 8 8 7 2 827 896 110 10 mgal6mn 1 78 26 62 130 220 45 8 mg 1 74 26 1 159 30 115 44 6 mgþni5 58 146 3 effectsonalmatrixcomposites andtheoptimalcontentoccursat0 5wt intherangeof34 38 furthermore themechanicalpropertiesofcnt inaddition carbonnanotubesinfluencethepropertiesofmgmatrix reinforced copper matrix nanocomposite studied daoush compositeaswell forexample zhengetal 83 reportedthatthetensile coworkers 85 theresultsshowedthatcntcangreatlyimprovethe property az31 mg matrix composite greatly improved yieldstrength withthehighestyieldstrengthachievedatthepointwhen introducing1wt mwnt moreover theeffectsofcntsonmechanical 15vol cntwasaddedintocoppermatrix daoushalsofoundthatthe propertiesoftimatrixcompositealsohavebeenstudiedbykondoh 84 young modulus cu matrix composite gradually increased forinstance asshowninfig 6 theadditionofmwntfrom0 18wt increasingcntcontent inadditiontothematricesofal mg ti andcu 0 35wt cancontinuouslyincreasethetensilestrength yieldstrength hwangetal studiedtheeffectsofmwntonthepropertiesofnimatrix hardness ti nanocomposites moreover addition composite 86 specifically theyoung smodulusandyieldstrengthof mwntdoesnotreducetheelongationoftianditscomposites whichis nicompositewereincreasedby21gpaand521mpawiththeincreaseof fig 6 themechanicalpropertiesoftheextrudedtiandits nanocomposites yieldstrength ultimatetensilestrengths andelongation b vickershardness 81 28x zhangetal progressinaerospacesciences97 2018 22 34 mwntfrom0to6vol respectively ofadditionalalloyelements although steelstillplaysanimportantrole intheaerospaceindustry especiallyforgears bearing carriage 3 4 3 polymermatrixcomposites fastener steel conventional aerospace industry alloy polymer matrix composite pmcs grouped two cate experienceda rapiddecreasein recent year dueto lower specific gories thermoplasticandthermoset basedonthedifferencesinmatrix strengthandcorrosionresistancethannewmaterialssuchaslightalloys characteristic theprominentadvantagesofpolymermatrixcomposites andcomposites 106 well known high specific strength specific modulus toovercometheseshortcomings recentstudiesfocusonthedevel example thedensityofcarbonfiber cf reinforcedepoxycompositeis opmentofnewlowalloysteelsandnanosteels whencomparedtocon onlyhalfthatofal basedalloyswhile thetensilestrengthandelastic ventional carbon steel low alloy steel show better performance modulusarethreetimesandtwotimeshigher respectively thanthoseof hardenability tempering softening capacity wear corrosion al basedalloy 89 theexcellentpropertiesoffiberscontributetoad resistance inrecentstudies themostattractivetypeoflowalloysteel vancesinpmcs andthepropertiesofsomefibersareshownintable 3 shown ultrahigh strength steel uhss uhss yield boththermosetandthermoplasticpmcshavebeenusedforaerospace strength 1380mpa due finer grain size precipitation structureapplicationssuchasailerons flap landing geardoors boeing strengthening 107 sometypicalutssare 4130 4140 4340 6150 777 787 airplane 50 weight cfrp 90 9260 300mandd6ac 106 108 thecompositions yieldstrengths althoughtheconventionalcfcanimprovethestrengthofpmcs thecf application typical ultra high strength low alloy steel reinforced composite likely suffer stress concentration demonstratedintable4 however uhssarepronetodegradationby becauseofthebrittlenessofcf 91 therefore recentinvestigationsof hydrogen h becausehydrogen atomsat crack tip weakeninter fibersforpmchavefocusedonthenaturalfibers 92 carbonnanotubes atomicbondsandfacilitatecrackgrowthbyslipandmicrovoid andthe 93 graphene 94 andbasalt 95 naturalfibers suchasflax hemp distributionofhydrogenishighlynonuniformunderanappliedstress banana bamboo andrecycledcellulosefiber rcf arebeingusedinthe cause localized deformation localized failure 109 polymersystemtoimprovethemechanicalpropertiesofpmc 96 li addition uhss recent developed nanostructure steel nano andcoworkers 97 reportedthe tensilestrengthofhigh densitypoly steelswithultra finegrains nanosizeparticles andnanosizephaseshave ethylene hdpe with20 flaxfiberistwicethatofhdpewithoutany beenstudied thenanosteelshaveahigherstrengthandbettercorrosion flaxcontent however themaindisadvantageofnaturalfibers polymer resistance due prevention dislocation movement nano compositesistheincompatibilitybetweenthehydrophilicnaturalfibers particle fewer defect surface steel

110 typical andthehydrophobicthermoplasticmatrix 98 inadditiontonatural example nanostructure steel 9cr oxide dispersion strengthened fiber reinforced pmcs carbon nanotube reinforced pmcs od steel strength 9cr od steel ys¼845mpa widely used military aircraft structure component uts¼915mpa higher conventional sae 2330 steel conductivecoatingsforfighterjets 99 accordingtoearlierworksby ys¼689mpa uts¼841mpa 111 qianetal 100 andbiercuketal 101 carbonnanotubescansignif icantly improve elastic modulus break strength hardness 3 6 ni basedsuperalloy polymercomposites however accordingtothereviewpaperbymittal andcoworkers 93 variousinvestigations 102 reportedthatwhenthe recent advanced ni based superalloys containing γ ni3 al ti content cnt exceeded critical point mechanical property phasewithhighvolumefractions resultingthehighstrengthofni based decreasedwithincreasingthecontentofcnt comparedtocntrein superalloysathightemperature 113 forexample thetensilestrength forced pmcs graphene based polymer composite much better ofawroughtni cr wsuperalloycanreachupto550mpaat800 cid 1 c 11 mechanicalproperties 103 forexample wanetal 104 reportedthat duetotheirhighstrengthathightemperature superalloysarewidely tensile strength epoxy composite increased 52 98mpa usedinsomeaeroenginepartssuchasthecombustorandturbinesection 71 54mpabyaddingonly0 1wt grapheneoxide go furthermore whereoperatingtemperaturesrangebetween1100and1250 cid 1 c 114 basalt another effective reinforcement pmcs recent test con theapplicationsofni basedsuperalloyinthepw4000engineareshown ducted zhang et al 105 showed tensile strength tensile infig 7 ni basedsuperalloyshaveshownlittleinherentresistanceto modulus flexuralstrength andflexuralmodulusofpolybutylenesucci high temperatureoxidation 113 chiouandcoworkers 115 reported nate continuously increased basalt fiber content increased thattheadditionofalimprovedtheoxidationresistance theoxidelayer from0to15vol thicknessofcm 247lcni basedsuperalloyatoxidationtimeof100h reduced 20μm 6μm adding 1wt al 3 5 steel formationofal2o3canpreventtheoutwarddiffusionofcationandin ward diffusion oxygen ion addition researcher steel used aerospace industry ever since first portedthattheadditionofchromiuminni basedsuperalloyimproves aircraftwasbuiltbythewrightbrothers withthedevelopmentofnew thehotcorrosionandoxidationresistance however thehighcontentof technology thecompositionofsteelhaschangedfromcarbonandiron cr reported detrimental microstructural stability 116 intoacomplexalloycombinedwiththeelementoffeandanabundance example chen et al 116 reported stress rupture life table3 propertiesofsomereinforcementsofcomposites 87 fiber densityg cm3 thermalconductivity young tensile straint o fracture hardness maximumservice w cid 1 c modulus strength failure toughness vickers temperature gpa mpa mpa m0 5 hv oc alfiber 3 5 22 5 305 2200 0 9 1 75 650 1000 alwhisker 3 96 22 5 455 1550 0 225 4 5 2350 1000 borsic 2 75 38 400 3000 0 75 3 900 550 gr 1 95 140 700 2200 0 75 1 5 700 600 sicwhisker 3 17 80 460 7000 0 225 2 75 950 1150 sic 3 18 80 465 2750 0 225 2 75 3250 1050 boroncarbide 2 5 19 400 2400 0 75 3 900 550 1 86 185 307 965 3 5 13 260 300 tidiboride 4 6 73 525 320 0 15 5 5 2750 1450 29x zhangetal progressinaerospacesciences97 2018 22 34 table4 thecompositions yieldstrength andapplicationsoftheultra highstrengthlowalloysteels 106 108 112 c mn si ni cr mo v co maximum application yieldstrength mpa aermet100 0 23 0 01 0 01 11 14 3 00 1 18 13 44 1700 shaftfittings landinggearsaxles turbinecomponents airframe 4130 0 31 0 50 0 28 0 95 0 20 1110 axle rotor gear fuselage snapsprings crankshaft 4140 0 41 0 88 0 28 0 95 0 20 1110 4340 0 41 0 70 0 28 1 83 0 80 0 25 2020 6150 0 51 0 80 0 28 0 95 0 20 1225 snapsprings propellercones gear shaft pinsandbolts 9260 0 60 0 88 2 00 1149 spring 300m 0 83 0 77 1 63 1 83 0 83 0 40 0 05 1689 landinggears airframe fastener d6ac 0 45 0 75 0 28 0 55 1 05 1 00 0 08 1379 landinggears spring shaft fig 7 theuseofni basesuperalloyinpw4000engine 117 ni basedsuperalloywith5 7wt ofcrwas3 7timeslongerthanthatof interfacebytheeffectofresidualamine intrinsicself healingismostly ni based alloy without cr content however high ratio cr undertheconditionofmanualintervention kauschetal 123 inves contentresultsintheformationofthetopologicallyclose packedphase tigatedthecrackhealingbehaviorofsomethermoplasticmaterialsand brittle depleted potent solid solution strengthening ele foundthatthestrengthcanberestoredbyheatingthesematerialsover mentsfromtheγ matrix theglasstransitiontemperaturebecauseoftheinterdiffusionofmolec ular entanglement glassy polymer wu et al 124 reviewed 4 newmaterialspotentialforaircraft self healingbehaviorforboththermosetandthermoplasticmaterialsand reported intrinsic self healing achieved

self reliant material self cleaning polymerics self method photo induced healing reversible bond formation repairing material potential high use flight vehicle healing chain end recombination self healing material self cleaning material found natural environment one potentially used aerospace industry self healing material exampleislotusleaves whenwaterispouredovertheseleaves itrolls containingboron b canbeusedforaircraftenginepartsthroughthe offasbeadsandtakesawaydirtontheleaves 118 themechanismsof formation b2o3 seal matrix crack high temperature self cleaning material divided two category first 121 inaddition someself healingmaterialssuchasself healinghol basedonthewettabilityofthesurface andthesecondoneisthepho lowglassfiber epoxycompositeswithexcellentfatigueresistancecanbe tocatalytic feature 119 120 hydrophobic surface potentiallyusedinaircraftstructuralapplicationsbecauseoftheability self cleaning material material interface protected polar tohealmicrocracksbeforecrackgrowthtofailure 121 furthermore moleculesabsorptionaswaterrollsoffthesurfacewiththedirt 5 light self healingmaterialssuchasself healingepoxycompositecanprotect captured photoactive surface process produce aircraftstructuresfromcorrosionbycoating becausetheycanrecover oxidative radical mineralize absorb organic molecule theirprotectabilityafterdamages 121 119 basedontheseproperties thematerialcanbeappliedtothefabric ofseatsandcarpetsinfutureaircraft 5 challengesfacedinthedevelopmentofrecentlyadvanced addition self cleaning material self repairing self healing material material widely studied researched last several de cades theself healingmaterialscanbepolymer ceramicormetalmatrix 5 1 frettingwear composite 121 self repairing material protect integrity structure maintain function material mechanical frettingweariscausedbysmall amplitude lessthanabout100µm damageandcorrosion theself healingmaterialscanbedividedintotwo oscillatory movement two contact body 20 125 fretting category whichareextrinsicself healingandintrinsicself healing wearcancreateinitiatecracksonthedamagedsurfaceandreducefa extrinsicself healingreliesonthehealingagent whichisstoredinma tigue life component 126 fretting wear occurs aircraft terials advance two type ofcontainers pipelinesandmicrocap structuralcomponentsandenginepartssuchasthebearingshaft bolted sules thecrackscanbere boundbythereleasingofhealingagentto connection andblade discassemblies 127 ti basedalloysmostlyare crackplanesbecauseofthecapillaryeffect zhangetal 122 notedthat used connect component often fretting thecrackshealingprocessismoreefficientbymixingepoxymonomer load whicheasilysufferfrettingdamage consequently recentstudies andsolvent itisbecausetheepoxymonomercanbecuredonthematrix offrettingbehaviorsfocusonti basedalloys 128 afewresearchers 30x zhangetal progressinaerospacesciences97 2018 22 34 haveconductedtestsseekingtoeliminatethefrettingwearbehaviorof 5 3 stresscorrosioncracking scc andhydrogenembrittlement aerospacematerials fuandcoworkers 129 investigatedthreemethods usedforfrettingdamageprevention newdesign surfacemodification stresscorrosioncrackingisconsideredasoneofthemostdangerous use lubricant widely studied method surface failuremechanismsbecausescccancauseslowcrackgrowthundera modification modification surface hardness adhesion safeloadingcondition whenthecracksizereachedthecriticalvalue 126 thedifferenceinhardnessbetweentwomatingpairscangreatly crackbysccwiththesafeloadingcancausethesuddenfailureofma influence fretting wear lemm et al 130 reported total net terials sccisresultedfromthree wayinteraction whicharemechanical wearvolumesofarangeofequal hardnesssteelpairs hardnessfrom250 stress susceptiblealloy andcorrosiveenvironment 142 themecha kgfmm cid 4 2to850kgfmm cid 4 2 aresimilar around0 45mm3 however nismsofheandsccarerelevantbecausehydrogeninitiallyoccursatthe total net wear volume experienced small reduction 0 35mm3 tipsofcracksinanaqueousenvironment 143 sccandhebehaviorsin increasing hardness difference 600 kgf mm cid 4 2 lemm somesusceptiblemetallicmaterialssuchassteels 144 al basedalloys co worker 130 alsoreportedthatthewearvolumeoftheharderpart 145 andmg basedalloys 146 havebeenwidelyinvestigated mghas canreachupto95 oftotalwearvolumebecauseoftheprotectionofthe ahighintrinsicdissolutiontendency andtheimpuritiesandthesecond softer part oxide based fretting wear debris sarhan et al 131 phase act local cathode accelerate corrosion local studied relation hardness fatigue life hard anodized galvanic whichcontributestothemg basedalloys susceptibilitytoscc al7075 t6aerospacealloy theresultsshowedthatfatiguelifeofthis addition mg based alloy al based alloy 3 5wt alloy optimized improving surface hardness 393 hv highercontentofmgarealsosusceptibleto scc itis knownthatthe low stressregions however thehardanodizedcoatinghasnoornega segregation mg along grain boundary facilitate hydrogen tiveeffectonfatiguelifeinhigh stressregions over200mpa zalnez entry acceleratethetransportofhydrogen andprovidesitesforgrain coworkers 132 reported improvement surface boundaryembrittlementbyhydrogenchemisorption 147 mgdissolv hardnesscangreatlyimprovethefatiguelifeofatincoatedal7075 t6 ingintoalformsthehighlyanodicβphaseofal3mg2 whichcanincrease alloy low cyclic fatigue improvement adhesion thesusceptibilityofal basedalloystoscc 142 148 inordertoprevent significantlyimprovethefatiguelifeinhigh cyclicfatigue otherprop sccandhe someelementshavebeenstudiedinrecentyearstoimprove ertiessuchastoughness frictionfactor andbondingstrengthalsohave crackingresistance 144 guo 149 studiedsomealloyingelementsin beeninvestigatedtopreventfrettingdamage duetal 133 reported mg basedalloysandreportedthemnelementhasapositiveeffectonthe thatbondingstrengthandtoughnesshaveagreatereffectthanthefric improvement scc resistance peng et al 150 reported scc tionfactoronfrettingwearresistanceofdiamond likeandgraphite like resistancewasincreasedwiththeincreaseofsizeandspacingofgrain carboncoatedti basedalloys althoughresearchershavestudiedfretting boundaryprecipitates gbp byreducingthepropagationrateandthe behavior material general theory describing fretting concentrationofatomichydrogen relatedly methodssuchastheoret behaviorandpreventionisstillnotmature 20 furtherworksshould icalandquantummechanicalmodels recentnano research andatom concentrate mechanism fretting develop effective isticinvestigationshavebeendevelopedtostudythemechanismofhe methodstoimprovefrettingresistance andscc however theapplicablepredictionapproachremainsnonex istentbecausethemechanismsofheandsccarenotaffectedbyone 5 2 corrosion parameterbutbymultiplefactorsincludingambientmedium mechan icalproperties andmanufacturingprocesses 151 152 corrosioninvolvesthechemicaldegradationofmaterialswhenthe materialsreacttotheirenvironment 134 corrosion suchasuniform 6 conclusionandfuturetrends corrosion pittingcorrosion crevicecorrosion orgalvaniccorrosion causefailureofcomponentswhentheremainingmaterialsaftercannot thepresentreviewshowsthatsignificantprogresshasbeenmadein support applied load moreover corrosion compromise com thedevelopmentofbothaircraftstructuralmaterialsandenginemate ponentsthatarepronetofailbyothermodes 135 metalcorrosioncan rial thedesigncriteriafortheaircraftstructuralmaterialsrequirethe causealossof 276billionperyearintheus muchgreaterthantheloss material posse appropriate mechanical property suitable causedbynaturaldisasters 21 basedontheprediction onlyupto30 damage tolerance different condition al based alloy corrosion loss avoided corrosion prevention method primarymaterialinthisfieldformanyyearsbecauseoftheirwell known 21 variousstudieshaveinvestigatedcorrosionbehaviorsindifferent mechanical behavior use polymer matrix composite material thereforeenablingthestraightforwardselectionofmaterials increasedinrecentyearsduetosuperiormechanicalpropertiessuchas foruseindifferentenvironments however somesuitablematerialsfor higherspecificstrengthandstiffnesswhencomparedtoal basedalloys corrosionresistancemaynotsupportotherrequirements forexample however conventional carbon fiber reinforced polymer matrix high corrosion resistance material always used aircraft compositesaremorelikelytosufferfromstressconcentration inaddi structuresbecauseofthestrength weightratio therefore methodshave tion use mg based alloy steel ti based alloy beendevelopedtopreventcorrosionofstructurematerials andthemost aerospaceapplicationsisrestrictedbysomechallenges thecriteriafor widelyinvestigatediscoating 21 thefunctionsofthecoatingare 1 aircraft engine require material provide suitable mechanical providealocalcorrosionbarrier 2 actasasacrificialanode 3 property density corrosion resistance high temperature supplysoluteions 136 however conventionalcorrosioncoatinghas compressor section temperature range difficulty providing active corrosion inhibitor therefore defect 500 600 cid 1 c ti basedalloysaretheprimarymaterials ni basedsuper protected transport inhibitor liquid alloy primary material high temperature corrosivephase 136 chromium 137 hasbeenstudiedasproviding 1400 1500 cid 1 c turbinesection efficientcorrosioninhibitors however chromiumhasbeenreportedto inthefuture specificmechanicalpropertiesandchallengessuchas causehealthproblemsandenvironmentdisastersinitshexavalentform frettingwear corrosion andsccwillbethemaindriversinthedevel 138 althoughsomeotherelements suchasgraphene 139 cerium opment selection next generation structure material sulphate 140 oxide rare earth element 141 airframe material dominated various material al studied improve protective performance mechanism based alloy ti based alloy steel composite work corrosionbehaviorandpreventionneedtobefurtherstudy airframematerialsshouldfocusonthefollowingthreetopics develop newmetalalloyswithhigherspecificmechanicalpropertiesbyvarious strategy includingmicrostructurerefinement impuritiescontrol thermal mechanical processing ii develop new method 31x zhangetal progressinaerospacesciences97 2018 22 34 compositionmodification coating andmicrostructurecontroltoover 29 x li j starink analysisofprecipitationanddissolutioninoveraged7xxx comethechallengesofmetalalloys includingmoreefficientprevention aluminiumalloysusingdsc 2000 30 v antipov etal high strengthal zn mg cualloysandlightal lialloys met methodforfrettingwearofti basedalloys moreefficientpredictionand sci heattreat 53 9 10 2012 428 433 preventionmethodsforcorrosion scc andheofal basedalloys mg 31 karabin f barlat r shuey finiteelementmodelingofplanestraintoughness based alloy steel iii develop new composite material for7085aluminumalloy metall mater trans 40 2 2009 354 364 mmc pmc balanced property fiber selection 32 ebrahimi etal themicrostructure hardnessandtensilepropertiesofanew superhighstrengthaluminumalloywithzraddition mater de 31 9 2010 futuretrendsofaircraftengine smaterialsfocusonhowtowithstandthe 4450 4456 risingenginetemperatureandmaintainthepropermechanicalproper 33 w nam h lee theeffectofmnonthemechanicalbehaviorofalalloys met mater int 6 1 2000 13 16 tie future work focus following topic 34 uddin etal effectofliadditiononmicrostructureandmechanicalproperties improvethehigh temperatureresistanceofti basedalloysbycontrolling ofal mg sialloy int j mater re 105 8 2014 770 777 phasesthroughalloyingandthermal mechanicalprocessing ii develop 35 uddin etal thesynergisticeffectofliadditiononmicrostructure textureand mechanicalpropertiesofextrudedal mg sialloys mater chem phys 174 advanced ni based superalloys alloying element prevent 2016 11 22 high temperatureoxidation suchasalandzr iii developtheadvanced 36 r wanhill aerospaceapplicationsofaluminum lithiumalloys aluminum cmcwithhigherfracturetoughnessbyrevealingtheoptimizedcontent lithiumalloys elsevier 2014 pp 503 535 offibers suchasgrapheneplatelet 37 h garmestani etal modelingtheevolutionofanisotropyinal lialloys applicationtoal li2090 t8e41 int j plast 18 10 2002 1373 1393 38 kalyanam etal delaminationcrackinginadvancedaluminum lithium reference alloy experimentalandcomputationalstudies eng fract mech 76 14 2009 2174 2191 39 p cavaliere etal 2198al liplatesjoinedbyfrictionstirwelding mechanical 1 dursun c soutis recentdevelopmentsinadvancedaircraftaluminiumalloys mater de 56 2014 862 871 andmicrostructuralbehavior mater de 30 9 2009 3622 3631 40 singh etal textureevolutionandanisotropyinal li cu mgalloys texture 2 e starke j staley applicationofmodernaluminumalloystoaircraft prog aero sci 32 2 3 1996 131 172 mater re 1999 219 234 3 warren developmentsandchallengesforaluminum aboeingperspective 41 tsivoulas p prangnell theeffectofmnandzrdispersoid formingadditionson recrystallizationresistanceinal cu liaa2198sheet actamater 77 2014 materialsforum citeseer 2004 1 16 4 r ap j p lir ci ao tija nj mli eu llh e av erlu tio ran f 4a 3l l 9i ba 2se 01p 2r od 3u 3c 2t 5 f 3o 3r 3a 7e rospaceandspace 42 p gregson etal roleofvacanciesincoprecipitationofδ0 ands phasesin al li cu mgalloys mater sci technol 2 4 1986 349 353 5 chen etal recentadvancesonthedevelopmentofmagnesiumalloysfor biodegradableimplants actabiomater 10 11 2014 4561 4573 43 ostrovsky andy henn presentstateandfutureofmagnesiumapplicationin 6 f czerwinski controllingtheignitionandflammabilityofmagnesiumfor aerospaceindustry aerospaceapplications corrosionsci 86 2014 1 16 44 chandrasekaran john effectofmaterialsandtemperatureonthe 7 r boyer r briggs theuseofβtitaniumalloysintheaerospaceindustry forwardextrusionofmagnesiumalloys mater sci eng a381 1 2004 j mater eng perform 14 6 2005 681 685 308 319 45 w jian etal ultrastrongmgalloyvianano spacedstackingfaults mater rese 8 cesedupackdatabse lett 1 2 2013 61 66 9 sommers etal ceramicsandceramicmatrixcompositesforheatexchangers inadvancedthermalsystems areview appl therm eng 30 11 2010 46 c bettles gibson currentwroughtmagnesiumalloys strengthsand

1277 1291 weakness jom57 5 2005 46 49 47 luo magnesiumcastingtechnologyforstructuralapplications j magnesium 10 g sim etal effectofnbprecipitatecoarseningonthehightemperature alloys1 1 2013 2 22 strengthinnbcontainingferriticstainlesssteels mater sci eng a396 1 2005 159 165 48 z wen etal corrosionbehaviorsofmganditsalloyswithdifferentalcontents 11 g bai etal effectoftemperatureontensilebehaviorofni cr wbased inamodifiedsimulatedbodyfluid j alloy comp 488 1 2009 392 399 superalloy materialsscienceandengineering a528 4 2011 1974 1978 49 b zhang l geng wang researchonmg zn caalloyasdegradable biomaterial intechopenaccesspublisher 2011 12 p j arrazola etal machinabilityoftitaniumalloys ti6al4vandti555 3 j mater process technol 209 5 2009 2223 2230 50 song etal theeffectofznconcentrationonthecorrosionbehaviorofmg xzn 13 g srinivasu etal tensileandfracturetoughnessofhighstrengthβtitanium alloy corrosionsci 65 2012 322 330 alloy ti 10v 2fe 3al asafunctionofrollingandsolutiontreatment 51 liu etal refinementeffectofcerium calciumandstrontiuminaz91 temperature mater de 47 2013 323 330 magnesiumalloy j mater process technol 209 8 2009 3999 4004 52 homma etal effectofzradditiononthemechanicalpropertiesofas extruded 14 z te ml piy ei rn ag ure et jl ah lli og yh c cy oc mle pf 5ti 0g 9ue 5p ro 2p 0er 1t 1y 2f 0t 8i 1 6 0 20 08a 6ll oyatambient mg zn ca zralloys mater sci eng a527 9 2010 2356 2362 53 xu etal effectofyconcentrationonthemicrostructureandmechanical 15 j wang etal themicrostructureevolutionanditseffectonthemechanical propertiesofas castmg zn zralloys j alloy comp 432 1 2007 129 134 propertiesofahot corrosionresistantni basedsuperalloyduringlong term thermalexposure mater de 39 2012 55 62 54 j krane etal ed proceedingsofthe2013internationalsymposiumon 16 zgün etal injectionmoldingofnickelbased625superalloy sintering heat liquidmetalprocessing casting springer 2016 55 j c williams e starke progressinstructuralmaterialsforaerospacesystems treatment microstructureandmechanicalproperties j alloy comp 546 2013 192 207 actamater 51 19 2003 5775 5799 56 l jing propertiesandapplicationsoftitaniumalloys nonferrousmetals 17 z alam etal effectofcyclicoxidationonthetensilebehaviorofdirectionally solidifiedcm 247lcni basedsuperalloyat870 cid 1 c mater sci eng a527 23 process 4 2002 002 2010 6211 6218 57 w jia etal ontheinfluenceofprocessingparametersonmicrostructural evolutionofanearalphatitaniumalloy mater sci eng a530 2011 135 143 18 z wang etal themicrostructureandmechanicalpropertiesofdeposited in718 byselectivelasermelting j alloy comp 513 2012 518 523 58 atapour etal corrosionbehaviorofβtitaniumalloysforbiomedical application mater sci eng c31 5 2011 885 891 19 n arivazhagan etal investigationonaisi304austeniticstainlesssteeltoaisi 59 x jiang etal structureandmechanicalpropertiesoftizrbinaryalloyafteral 4140lowalloysteeldissimilarjointsbygastungstenarc electronbeamand frictionwelding mater de 32 5 2011 3036 3050 addition mater sci eng a586 2013 301 305 20 k sikdar shekhar k balani frettingwearofmg li albasedalloys wear318 60 r boyer r briggs theuseofbetatitaniumalloysintheaerospaceindustry 1 2014 177 187 j mater eng perform 22 10 2013 2916 2920 61 song etal theoreticalstudyoftheeffectsofalloyingelementsonthestrength 21 kesavan gopiraman n sulochana greeninhibitorsforcorrosionofmetals areview chem sci rev lett 1 1 2012 1 8 andmodulusofβ typebio titaniumalloys mater sci eng a260 1 1999 269 274 22 z huda p edi materialsselectionindesignofstructuresandenginesof supersonicaircrafts areview mater de 46 2013 552 560 62 x zhao etal betatypeti moalloyswithchangeableyoung smodulusforspinal fixationapplications actabiomater 8 5 2012 1990 1997 23 c veiga j davim loureiro propertiesandapplicationsoftitaniumalloys briefreview rev adv mater sci 32 2 2012 133 148 63 j cotton etal stateoftheartinbetatitaniumalloysforairframeapplications jom67 6 2015 1281 1303 24 p zhang etal plasticdeformationbehaviorandprocessingmapsofani based superalloy mater de 2015 65 1980 2015 575 584 64 j lu etal precipitationbehaviorandtensilepropertiesofnewhighstrength betatitaniumalloyti 1300 j alloy comp 637 2015 1 4 25 banerjee etal effectoftraceadditionsofsnonmicrostructureandmechanical propertiesofal cu mgalloys mater de 31 8 2010 4007 4015 65 j wood etal thermomechanicalprocessingandheattreatmentof ti 6al 2sn 2zr 2cr 2mo siforstructuralapplications mater sci eng a243 26 e salamci mechanicalpropertiesofspraycast7xxxseriesaluminiumalloys turk j eng environ sci 26 4 2002 345 352 66 1 q u1 9 e9 t8 l1 0 b9 e h1 a1 v8 io randmodelingofhightemperaturedeformationofanαþβ 27 j yu x li modellingoftheprecipitatedphasesandpropertiesofal zn mg cu titaniumalloy mater sci eng a555 2012 99

105 alloy j phaseequilibriadiffusion32 4 2011 350 67 zhu etal
characterizationofhotdeformationbehaviorofas casttc21 28 eling aluminiumalloys availablefrom http
www eling r titaniumalloyusingprocessingmap mater sci eng a528 3 2011 aluminiumalloys html 1757
1763 32x zhangetal progressinaerospacesciences97 2018 22 34 68 c cui etal
titaniumalloyproductiontechnology marketprospectsand 106 prasad n e andr wanhill
aerospacematerialsandmaterialtechnologies industrydevelopment mater de 32 3 2011 1684 1691 107 j
r davis alloying understandingthebasics asminternational 2001 69 zherebtsov etal
mechanicalpropertiesofti 6al 4vtitaniumalloywith 108 g murray
handbookofmaterialsselectionforengineeringapplications crc
submicrocrystallinestructureproducedbysevereplasticdeformation 2005 press 1997 70 r h hu j k lim
hardnessandwearresistanceimprovementofsurface 109 j c cid 2 wiek
preventionmethodsagainsthydrogendegradationofsteel j achiev compositelayeronti 6al
4vsubstratefabricatedbypowdersintering mater mater manuf eng 43 1 2010 214 221 design 1980 2015
31 5 2010 2670 2675 110 f buazar cheshmehkani kassaee nanosteelsynthesisviaarcdischarge 71 r jing
etal structureandmechanicalpropertiesofti 6al 4valloyafter mediaandcurrenteffects j iran chem soc 9 2
2012 151 156 zirconiumaddition mater sci eng a552 2012 295 300 111 k mo etal
synchrotronstudyonloadpartitioningbetweenferrite martensite 72 l pilato j michno
advancedcompositematerials springerscience andnanoparticlesofa9crodssteel j nucl mater 455 1 2014
376 381 businessmedia 1994 112 uluc etal theroleofheattreatmentandalloyingelementsonhydrogen 73 j
pora compositematerialsintheairbusa380 fromhistorytofuture uptakeinaermet100ultrahigh strengthsteel
j electroanal chem 739 2015 proceedingsoficcm13 plenarylecture cd rom 2001 130 136 74 ahmad b
yazdani zhu recentadvancesoncarbonnanotubesandgraphene 113 e ezugwu z wang machado
themachinabilityofnickel basedalloys reinforcedceramicsnanocomposites nanomaterials5 1 2015 90
114 review j mater process technol 86 1 1999 1 16 75 fan etal
progressofceramicmatrixcompositesbrakematerialsforaircraft 114 soo etal
machinabilityandsurfaceintegrityofrr1000nickelbased application rev adv mater sci 44 2016 313 325
superalloy cirpann manuf technol 60 1 2011 89 92 76 l walker etal
tougheningingrapheneceramiccomposites acsnano5 4 115 chiou etal
effectsofaluminumadditiononthehightemperature 2011 3182 3190 oxidationbehaviorofcm 247lcni
basedsuperalloy int j electrochem sci 10 77 j liu h yan k jiang mechanicalpropertiesofgrapheneplatelet
reinforced 2015 5981 5993 aluminaceramiccomposites ceram int 39 6 2013 6215 6221 116 j chen etal
improvementofstress rupturepropertybycradditioninni based 78 j liu j li c xu
interactionofthecuttingtoolsandtheceramic reinforcedmetal singlecrystalsuperalloys mater sci eng a528
10 2011 3791 3798 matrixcompositesduringmicro machining areview cirpj manuf sci technol 117 locq p
caron onsomeadvancednickel basedsuperalloysfordisk 7 2 2014 55 70 application aerospacelab 3
2011 1 9 79 prater frictionstirweldingofmetalmatrixcompositesforuseinaerospace 118 compony
futuretechnologies availablefrom http www airbus com structure actaastronaut 93 2014 366 373
innovation future airbus concept plane airbus concept cabin future 80 moghadam etal
mechanicalandtribologicalpropertiesofself lubricating technology
metalmatrixnanocompositesreinforcedbycarbonnanotubes cnts 119 g soliveri etal doublesideself
cleaningpolymericmaterials thehydrophobic graphene areview compos partbeng 77 2015 402 420
andphotoactiveapproach colloid surface physicochem eng aspect 483 81 c tjong
recentprogressinthedevelopmentandpropertiesofnovelmetal 2015 285 291
matrixnanocompositesreinforcedwithcarbonnanotubesandgraphene 120 p parkin r g palgrave self
cleaningcoatings j mater chem 15 17 2005 nanosheets mater sci eng rrep 74 10 2013 281 350 1689
1695 82 j z liao j tan sridhar sparkplasmasinteredmulti wallcarbonnanotube 121 r da c melchior k
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