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highstrengthaluminiumalloysremainimportantinairframeconstruction aluminiumisarela aluminiumalloys tivelylowcost lightweightmetalthatcanbeheattreatedandloadedtorelativelyhighlevelofstresses al lialloys anditisoneofthemosteasilyproducedofthehighperformancematerials whichresultsinlowerman composite mechanicalproperties ufacturing maintenance cost important recent advance aluminium aircraft alloysthatcaneffectivelycompetewithmoderncompositematerials thisstudycoverslatestdevelop mentsinenhancedmechanicalpropertiesofaluminiumalloys andhighperformancejoiningtechniques themechanicalpropertiesonnewlydeveloped2000 7000seriesaluminiumalloysandnewgeneration al lialloysarecomparedwiththetraditionalaluminiumalloys theadvantagesanddisadvantagesof thejoiningmethods laserbeamweldingandfrictionstirwelding arealsodiscussed cid 2 2013elsevierltd allrightsreserved 1 introduction increasing tensile strength elastic modulus damage tolerance 1 airframe durability another parameterthat directly affect thecostreductionforaircraftpurchaseandoperationhasbe cost cost service maintenance 30 year life come driving force many airline company cost reduction oftheaircraftareestimatedtoexceedtheoriginalpurchaseprice canbeachievedbydecreasingthefuelconsumption maintenance byafactoroftwo 1 therefore bothmaterialproducersandair cost operational cost frequency periodical control craftdesignersareworkinginharmonytoreduceweight improve increasingtheservicelifeandcarryingmorepassengersatatime damage tolerance fatigue corrosion resistance new therefore aircraft manufacturer competing meet metallicalloys asaresult nearfutureprimaryaircraftstructures requirementsoftheirairlinecustomers weightreductioncanim willshowanextendedservicelifeandrequirereducedfrequency prove fuel consumption increase payload increase range ofinspections additionally improved optimised mechanical property compositematerialsareincreasinglybeingusedinaircraftpri thematerialscanresultinincreasedperiodbetweenmaintenance mary structure b787 airbus a380 f35 typhoon fig 1 andreducerepaircosts sincethematerialhasagreatimpacton showstheincreasedusageofcompositesinseveraltypesofboeing costreduction airframemanufacturersandmaterialproducersfo aircraft theattractivenessofcompositesinthemanufacturingof cu development new material meet customer high performance structure relies superior mechanical requirement hence current challenge develop material propertieswhencomparedtometals suchashigherspecificstiff thatcanbeusedinfuselageandwingconstructionwithimprove ness specificstrength normalisedbydensity fatigueandcorro mentsinbothstructuralperformanceandlifecyclecost according sion resistance although composite thought tothedesigntrialsitisseenthataneffectivewayofreducingthe preferablematerial wingand fuselage structure higher aircraftweightisbyreducingthematerialdensity itisfoundthat certificationandproductioncosts relativelylowresistancetoim decrease density 3 5 time effective pactandcomplicatedmechanicalbehaviourduetochangeinenvi ronmental condition moisture absorption getting soft brittle exposed hot cold environment make designer ex correspondngauthor tel 903128475300 plorealternativematerialsystems fibremetallaminates suchas e mail address tdursun aselsan com tr dursun constantinos soutis glare combine aluminium layer glass fibre epoxy manchester ac uk c soutis 0261 3069 seefrontmatter cid 2 2013elsevierltd allrightsreserved http dx doi org 10 1016 j matdes 2013 12 002t dursun c soutis materialsanddesign56 2014 862 871 863 ply improve tensile strength importantly damage alclad 2524 t3 sheet 2524 t351 plate fuselage tolerance finding great use aerospace application 3 12 skin theyalsodeveloped7150 t7751extrusionsforthesupport impactresistance effectofdamageonstiffness strengthespecially ing member fuselage structure application whenloadedincompressionanddamageidentificationanddetec material saved thousand pound weight boeing tion addition joint repair recycling remain big chal 777 19 lengesforcompositeswiththeneedoffurtherresearch 13 18 aircraft manufacturer also working decrease aluminiumalloyshavebeentheprimarystructuralmaterialfor number part new aircraft need could met commercialand militaryaircraft almost 80years due applying several approach first method producing large well known mechanical behaviour easiness design mature andthickplateshavingfatigueandfracturecharacteristicsequiv manufacturing process inspection technique alenttothoseofathinplate thesecondmethodisimplementa mainsoforsometimetocome however thenon metallicmate tion joining technology friction stir welding rial despite issue mentioned earlier due superior allows manufacture large integrally stiffened panel specificstrengthpropertiesprovideaverycompetitivealternative canbeusedforwingandfuselageskins 20 aluminium producer need keep investing put great review article cover latest development related effort improving thermo mechanical propertiesof alu aluminium alloy used aircraft primary structure high miniumalloystheyproduce lightsperformanceimprovementsinthe2000 7000seriesalumin density strength young smodulus fatigueresistance fracture iumalloysaswellasthenewgenerationofal lialloys currently toughness corrosion resistance important parameter the7000seriesal znalloysareusedwherethemainlimitingde thatneedtobeimproved dependingontheparticularcomponent sign parameter strength 2000 series al cu alloy used underconsideration materialpropertieshavetooutperformthose fatiguecriticalapplicationssincethesealloysaremoredamagetol offered polymer composite chemical composition erant whileal lialloysarechosenwherehighstiffnessandlower processing control microstructural feature precipi density required advantage disadvantage tate dispersoids degreeofrecrystallization grainsizeandshape joining technique laser beam welding friction stir welding crystallographic texture intermetallic constituent particle arealsodiscussed property affect physical mechanical corrosion characteristic aluminiumalloys therefore material producer 2 developmentsin2000seriesal cualuminiumalloys workingcloselywithaircraftdesignerscouldesigndifferenttypes metallic alloy physical mechanical property thealuminium copper 2000series alloysaretheprimaryal havebeentailoredtothespecifiedneeds forinstance theupper loys used airframe structural application main de sideofthewingismainlysubjectedtocompressionloadingduring sign criterion damage tolerance 2000 series alloy flight butalsoexposedtotensionduringstaticweightandtaxiing containing magnesium higher strength resulting opposite happens lower part wing hence precipitation al cu al cumg phase superior damage 2 2 carefuloptimisationoftensileandcompressivestrengthproperties tolerance good resistance fatigue crack growth compared isrequired damagetolerance fatigueandcorrosionresistanceare tootherseriesofaluminiumalloys 2024and2014arewellknown also needed making selection optimisation examplesforal cu mgalloys itiswellknownthatduetodiffer challenging ent loading condition component airframe requires design boeing 777 aluminium manufacturer different material property optimum reliable design asked improvement upper wing structure fuse thefuselageissubjecttocabinpressure tension andshearloads lage highercompressiveyieldstrengthwasneededfortheupper longitudinalstringersareexposedtothelongitudinaltensionand wingstructure improvedcorrosionresistancewasalsodesirable compression load due bending circumferential frame case fuselage higher damage tolerance durability tosustainthefuselageshapeandredistributeloadsintotheskin thantheincumbent2024 t3wasneeded aluminiummanufactur strength stiffness fatiguecrackinitiationresistance fatiguecrack ersaccountingforthedesigner sneedsdevelopedthe7055 t7751 growth rate fracture toughness corrosion resistance plate 7055 t77511 extrusion upper wing structure important fracture toughness resistance crack growth fig 1 combinationofmaterialsusedinboeingaircrafts thefigureisbasedon 2 864 dursun c soutis materialsanddesign56 2014 862 871 often limiting design parameter 21 wing 3 developmentsin7000seriesal znaluminiumalloys

consideredasacantilevertypeofbeamthatisloadedinbending flight also torsion wing support static
the7000seriesofaluminiumalloysshowhigherstrengthwhen
weightoftheaircraftandanyadditionalloadssubjectedinservice
comparedtootherclassesofaluminiumalloysandareselectedin additional wing load also come landing gear thefabricationofupperwingskins stringersandhorizontal verti taxiing take landing leading trailing calstabilizers thecompressivestrengthandthefatigueresistance edge flap slat deployed take arethecriticalparametersinthedesignofupperwingstructural landing create additional low speed lift upper surface component tail airplane also called empennage wing primarily loaded compression consists horizontal stabilizer vertical stabilizer fin upward bending moment flight loaded controlsurfacese g elevatorsandrudder structuraldesignofboth tension taxiing 21 chemical composition mechan thehorizontalandverticalstabilizersisessentiallythesameasfor ical property 2000 series aluminium alloy widely thewing bothби theupperandlowersurfacesofthehorizontalsta used airframe design given table 1 2 bilizer often critical compression loading due bending respectively 21 2024 t3 one widely used alloy highstrengthaluminiumalloyssuchasthe7075 t6arewidely fuselage construction moderate yield strength good usedinaircraftstructuresduetotheirhighstrength weightra resistance fatigue crack growth good fracture toughness tio machinability relatively low cost however due
the2024aluminiumalloyremainsasanimportantaircraftstruc composition alloy susceptible corrosion well tural material due extremely good damage tolerance
knownthatcorrosionreducesthelifeofaircraftstructuresconsid
highresistancetofatiguecrackpropagationint3agedcondition erably normal operation aircraft subjected natural low yield stress level relatively low fracture toughness corrosive environment due humidity rain temperature oil limit application alloy highly stressed region hydraulicfluidsandsaltwater
amongtheissuesfacingageingair 23 microstructural effect fatigue property alumin craft corrosionincombinationwithfatigueisextremelyundesir ium alloy investigated intensively improvement able 27 compositional control processing continually produced 7000 series alloy also heat treatable al zn new alloy known inclusion substantial effect mg
cuversionsprovidethehigheststrengthsofallaluminiumal onthefatiguecrackpropagation
higherfracturetoughnessvalues loys 7000 series alloy contain 2 copper
andbetterresistancetofatiguecrackinitiationand crackgrowth
combinationwithmagnesiumandzinctoimprovetheirstrength wereachievedbyreducingimpurities
especiallyironandsilicon thesealloysalthougharethestrongesttheyaretheleastcorrosion
ithasbeenannouncedthatforthefuselageapplicationsthealloy resistant 7000 series however newer 7000 series alloy 2524 t3 15 20 improvement fracture toughness introduced higher fatigue corrosion resistance twice fatigue crack growth resistance 2024 t3 24 mayresultinweightsavings
neweralloyssuchasthe7055 t77 improvement lead weight saving 30 40 longer service
havehigherstrengthanddamagetolerancethanthe7075 t6 1 life 25
the2524aluminiumalloyhasreplacedthe2024asfuse 7475 al zn mg cu aluminium alloy modified version lageskinintheboeing777aircraft fatiguetestsonthe2524alloy of7075alloy
the7475alloyisdevelopedforapplicationsthatre showed fatigue strength alloy 70 yield quire combination higher strength fracture toughness strength whereas 2024 t351 fatigue strength 45 resistance fatigue crack propagation air corrosive theyieldstrength 26 forthelowerwingskinapplications 27 environment strength fracture toughness property 2224 t351 2324 t39 alloy offer higher strength value 7075alloyareimprovedbydecreasingitscontentsofironandsil compared incumbent 2024 t351 similar fracture tough icon andchangingbothquenchingandageingconditions theto ness corrosion resistance compared 2024 composi talironandsiliconcontentin7075is0 90 whereasin7475the tional processing change 2224 t351 2324 t39 totalcontentislimitedto0 22 thesechangesinthe7075alloy alloy resulted improved property lower volume fraction resulted development 7475 alloy intermetallic compound improved fracture toughness fine grain size optimum dispersion highest toughness value stancethemaximumironcontentis0 12 andsiliconis0 10
amongthealuminiumalloysavailableathighstrengthlevel itis 2224 t351 whereas 2024 0 50 impurity newly also reported corrosion resistance corrosion fatigue
developedaluminiumalloy2026isbasedon2024butitcontains behaviour 7475 alloy excellent general perfor fewerimpuritiessuchasironandsilicon additionally 2026con mance better much commercially

available high tainsasmallamountofzirconiumwhichinhibitsrecrystallization strengthaerospacealuminiumalloyssuchas7050and7075alloys 28 2026 higher damage tolerance higher tensile strength 23 yieldstrength elongation andk propertiesofwidelyused ic higher fatigue performance acceptable fracture toughness 2024and7075alloysarecomparedwith7050and7475infig 2 comparedto2024and2224 29 itmaybeseeninfig 2thatthe2024 t351alloyhashighduc althoughthecontributionofcuandmginintermetallicphases tilityandgoodfracturetoughness bothintlandltorientations result high strength however due intermetallic phase buthasrelativelylowyieldstrength ontheotherhand the7075 particle corrosion resistance alloy significantly drop alloy t651 temper condition yield strength several investigation done order increase 500mpa reported fracture toughness alloy 7075 p corrosionandfatigueresistanceof2000seriesalloys 30 32 t651 tl lt orientation nearly 24mpa table1 chemicalcompositionofsome2000seriesaerospacealuminiumalloys 22 2000series cu zn mg mn fe si cr zr ti al 2024 4 4 1 5 0 6 60 5 60 5 0 1 0 15 remainder 2026 3 6 4 3 0 1 1 0 1 6 0 3 0 8 0 07 0 05 0 05 0 25 0 06 remainder 2224 4 1 1 5 0 6 60 15 60 12 remainder 2324 3 8 4 4 0 25 1 2 1 8 0 3 0 9 0 12 0 1 0 1 0 15 remainder 2524 4 0 4 5 0 15 1 2 1 6 0 45 0 7 0 12 0 06 0 05 0 1 remaindertable2 mechanicalpropertiesofsome2000seriesaerospacealuminiumalloys 22 2000series ut mpa yieldstrength mpa fracturetoughness kic mpam1 2 elongation 2024 t351 428 324 37 21 2026 t3511 496 365 na 11 2224 t39 476 345 53 10 2324 t39 475 370 38 5 44 0 8 2524 t3 434 306 40 tl 24 p 27mpa respectivelywhichcorrespondstolowlevelofductil ity 7475 t7351 alloy higher fracture toughness p p 42mpa 52mpa tl lt orientation respec tively whereas incomparisontothe7075 t651alloy the7475 t7351 alloy marginally inferior yield strength slightly superiorductility inviewofthesefacts theuseofappropriately treated7475alloyisexpectedtosafelyreducetheoverallweight ofaerospacestructure animportantcriterionforsuchapplications 23 infig 3fatiguecrackgrowthratesfordifferentaluminiumal loys compared shown 7475 higher fatigue resistancecomparedtothe2024 whilethe7075 t6hasthelowest fatigueresistance corrosion resistance fatigue behaviour alloy 7475 equalto orbetterthanmanyofthehighstrengthaluminiumalloys suchasthe7075 7050and2024 alloy7475plateandsheetare currently selected fracture critical component high performanceaircraftapplications 33 alloy7050isanotherimportantalloyhavingthegoodbalance strength stress corrosion cracking scc resistance recent alloy 7055 t7751 al 8zn 2 05mg 2 3cu toughness particularly suited plate application 0 16zr hasayieldstressthatmayexceed620mpaandtheesti 76 152mm thickness range alloy 7050 exhibit better tough mated weight saving attributed use component ness corrosion resistance characteristic alloy 7075 boeing aircraft 777 635kg 34 alloy provided nearly itislessquenchsensitivethanmostaerospacealuminiumalloys 10 gaininstrength withhighertoughnessandsignificantlyim 7050 retainsits strength propertiesin thickersections provedcorrosionresistance 24 t77temperconsistsofthreestep maintaininggoodstresscorrosioncrackingresistanceandfracture ageingprocessthatproducesahigherstrengthanddamagetoler toughnesslevels typicalapplicationsforalloy7050platesinclude ance combination compared 7050 t76 7150 t651 fuselage frame bulkhead section thickness t7751 improved fracture toughness result controlled 50 152mm ontheotherhandalloy7050sheetsareusedinwing volumefractionofcoarseintermetallicparticlesanduncrystallized skinsapplications long termcontrolledandin serviceevaluations grainstructure goodcombinationofstrengthandcorrosionresis shown alloy 7050 plate sheet product remain tanceisattributedtothesizeandspatialdistributionandthecop equal exfoliation stress corrosion resistance higher stress percontentofthestrengtheningprecipitates level compared high strength aluminiumalloys thereexistsacontinuousimprovementinthemechanicalprop as7075 erties aerospace aluminium alloy resulted development ofhigh strength 7xxxalloys e g 7075 7150 7055 7449 inchronologicalorderofapplication thesehighstrengthal 600 loys generally used compression dominated part upperwingskinswheredamagetoleranceconsiderationsaresec 500 ondary however recentdevelopmentsshowthatmodificationsin solutecontentandinparticularinzn mg curatioscanenablethe developmentof highstrengthproducts withsignificantimprove 400 ments damage tolerance aa7040 aa7140 aa7085 7085 developed new generation high 300 strengththickplatealloytobealternativefor7050 7010products due higher zinc lower cu content higher fracture toughnessandslowquenchsensitivitywereobtained thisproduct 200 wasselectedforwingsparapplicationsontheairbusa380 isalsoaneffforttoobtainagoodcombinationofhighstrengthand 100 good corrosion resistance application different heattreatmentmethods 35 twoimportantmetallurgicalprinci plesresultinginimprovementsare adecreaseinthemg znratio 0 2024 t351 7050 t73651 7075 t651 7475 t7351 andanoverallreductioninsaturationofthecompositionwithre specttothetheoreticalmaximumsolubility thestrongimpactof mgconcentrationincreasesonstrength beneficial andontough ness detrimental well known basis mg zn adjust ments observation partial replacement mg 2 1m apm1 0xc■k 1 0xle apm sy dursun c soutis materialsanddesign56 2014 862 871 865 fig 3 ncurvesfordifferentaluminiumalloys 23 yield strength elongation k■c tl direction k■c lt direction fig 2 comparative representation yield strength elongation kic differentaluminiumalloys thefigureisbasedon 23 866 dursun c soutis materialsanddesign56 2014 862 871 zn aslightlylesseffectivehardenerperwt enablesanincrease fracturetoughnessproblembeingoneofprimarilylowstrengthin toughness maintaining adequate strength overall theshorttransversedirection 1 21 44 45 reductioninsolutesaturationdirectlyaffectsthequenchsensitiv thepressureforhigherstrengthandimprovedfracturetough ity whichiscriticalfordamagetolerancepropertiesofhighsolute nesswithreducedweightinaircraftapplicationshaveresultedin alloy aa7056 t79 developed upper wing skin large thedevelopmentofnewgenerationofal lialloys thenewgener commercial aircraft good example improvement ationofal lialloysprovidesnotonlyweightsavings duetolower strength toughness balance 34 hand addition density butalsoovercomesthedisadvantageofthepreviousprob ofmnandzrinaluminiumalloyscanformfinedispersoidswhich lem increased corrosion resistance good spectrum fatigue affect recrystallization characteristic grain structure crackgrowthperformance agoodstrengthandtoughnesscombi dispersoidsretards recrystallization grain growth zr content nationandcompatibilitywithstandardmanufacturingtechniques inaluminiumalloyscanforma1 zrdispersoid whichhavearela result well balanced light weight high performance 3 tionship matrix significantly refines grain size aluminium alloy 1 44 46 new generation 3rd al li addition zn increase strength alloy whereas alloysliconcentrationwasreducedto0 75 1 8wt theaddition addition mn increase fracture toughness alloy ofalloying element 3rd generational lialloys used due formation secondary phase containing mn improve mechanical property poor corrosion resistance fe whichdecreasestheadverseeffectsoffeonfracturetoughness 2nd generation al li alloy eliminated 3rd generation al li 36 chemicalcompositionofsomeoftheimportant7000series alloy optimising alloy composition temper also zn aluminiumalloysaregivenintable3 addition improved corrosion resistance addition cu li fretting aspecialtypeofwearprocessthatoccursatthecon mg form strengthening precipitate small addition tact area two material load subject dispersoid forming element zr mn control grain small amount relative motion another important issue structure crystallographic texture thermo mechanical neededtobeunderstoodinbolted pinnedaircraftjoints thereis processing crack deviation occurs due high crystallographic current focus prevention fretting aerospace texture addition slip planarity deviation expected industrysinceduetofretting crackscaninitiateatstresses fret directionofcrackpropagationmakesitdifficulttodefineinspec ting zone well fatigue limit non fretted material tionpointsandthepositioningofcrackarresters itwasfoundthat andthe structure resistancetofatiguecanbedecreasedby 50 inadditiontoreductionofthetexturecomponents theseverityof 70 introduction compressive residual stress surface slipplanarityhadtobedecreased thisreductionwasachievedby ofhole reductionincoefficientoffriction increasedsurfacehard decreasing amount al li phase achieved 3 ness changing surface chemistry increasing surface keepingtheamountofliadditionsbelow1 8wtptc thefracture roughness main method applied reduce toughnessof2ndgenerational lialloyswasoftenlowerthanthe nucleationandgrowthoffrettingcracksand improvethefatigue incumbent 2024 alloy product design damage toler lifeofaerospacejointsandimprovefrettingresistance 37 42 ance driving parameter determined fracture toughnessisaffectedonlybyinsolublesecond phaseparticles 4 developmentsinaluminium lithiumalloys 3rdgenerational lialloyslike2199thisdisadvantageouscondi tion eliminated composition optimisation thermal reducingthedensityofmaterialsisacceptedasthemosteffec mechanicalprocessingandprecipitatemicrostructurecontrol tive way lowering structural weight aircraft li density chemical composition mechanical property 0 54g cm3 isoneofthefewelementsthathaveahighsolubility widely used al li alloy shown table 4 5 aluminium significant 1 added respectively densityofanaluminiumalloyisreducedby3 lithiumisalsoun alloy 2195 new generation al li alloy lower copper iqueamongstthemoresolublealloyingelementsinthatitcausesa contentandhasreplacedthe2219forthecryogenicfueltankon considerable increase elastic modulus 6 1 li thespaceshuttlewhereitprovidesahigherstrength highermod added additionaladvantageisthat aluminiumalloyscontaining ulusandlowerdensitythanthe2219 otheralloys includingthe lirespondtoagehardening 43 2096 2097 2197 also lower copper content also theuseofaluminium lithium al li alloysinaerospaceappli haveslightlyhigherlithiumcontentsthan2195 1 newgenera cationsgoesbackto1950swiththedevelopmentofalloy2020 tionofal lialloyshavehighercu liratiothanthesecondgener the1980s 2ndgenerationofal lialloysweredeveloped thesec ationalloys 2090and2091 asillustratedinfig 4 ondgenerationalloysincludedthe2090 2091 8090and8091 thenewgenerationof2199al lialloyssheetandplatesfound al lialloys2090 2091 8090and8091contain1 9 2 7 lithium application aircraft fuselage lower wing applica whichresultsinanabout10 lowerdensityand25 higherspe tions respectivelyandthe2099extrusionsforinternalstructure cificstiffnessthanthe2000and7000seriesalloys however due determined 2199 t8e79 plate lower wing totechnicalproblemssuchasanisotropyinthemechanicalprop skin 2099 t83 extrusion lower wing stringer erties lowtoughness poorcorrosionresistance manufacturingis 2199 t8 prime sheet fuselage skin would provide sue hole cracking delamination drilling 2nd benefitforthegivenapplicationsexamined itisstatedthatcom generational lialloysdidnot findwideuse inaircraftindustry pared 2024 2199 plate lower density significantly theanisotropyexperiencedbythesealloysisaresultofthestrong betterstresscorrosionandexfoliationcorrosionresistance signif crystallographictexturesthatdevelopduringprocessing withthe icantlybetterspectrumfatiguecrack growthperformance better table3 chemicalcompositionofsome7000seriesaerospacealuminiumalloys 22 7000series cu zn mg mn fe si cr zr ti al 7050 2 3 6 2 2 25 60 15 60 12 0 1 remainder 7055 2 0 2 6 7 6 8 4 1 8 2 3 0 05 0 15 0 1 0 04 0 08 0 25 0 06 remainder 7075 1 2 2 0 5 1 6 1 2 1 2 9 0 3 0 5 0 4 0 18 0 28 0 2 remainder 7150 1 9 2 5 5 9 6 9 2 0 2 7 0 1 0 15 0 12 0 04 0 08 0 15 0 06 remainder 7475 1 2 1 9 5 2 6 2 1 9 2 6 0 06 0 12 0 10 0 18 0 25 0 06 remaindert dursun c soutis materialsanddesign56 2014 862 871 867 toughness higher tensile yield compressive yield table5 strength ultimate tensile strength bearing shear mechanicalpropertiesofsomeal lialloys 22 strengthsforthet8e80temperaresimilartothosefor2024 al li ut yieldstrength fracture elongation forthet8e79temper thesestrengthstendtobelower however alloy mpa mpa toughness reduction tensile yield strength provides higher spec kic mpam1 2 trumfatiguecrackgrowthperformance thus oneofthetwotem 2050 t84 540 500 43 lt na pers 2199 may suitable given application 2090 t83 531 483 43 9 3 2098 t82 503 476 na 6 dependingonthedesigncriterion 44 2099 t83 543 520 30 lt 7 6 al li2099alloyhaslowdensity highstiffness superiordam 27 tl age tolerance excellent corrosion resistance weldability 2199 t8 400 345 53 10 useinaerospacestructuresthatrequirehighstrength alloy2099 8090 t851 500 455 33 lt 30 tl 12 extrusion replace 2xxx 6xxx 7xxxaluminiumalloys 12 4 sl application statically dynamically loaded fuselage structure lower wing stringer 2nd generation al li alloy weresusceptibletocrackinganddelaminationduringinstallation improved stress corrosion resistance without redesign ofinterferencefitfastenersasaresultofcoldworking lowelonga whenstrength stiffness fatiguepropertiesare takenintoac tionandworkhardeningpropertiesweretheresultsoftheseprob count itcanleadtoweightreductionuptoatotalofabout10 lem 3rd generation al li alloy elongation cold dependingonthepartdesigndrivers working capability improved alloy 2099 extrusion al lialloy2198wasdevelopedtoreplace2024and2524inair goodmachining forming fastening andsurfacefinishingproper craftstructureswheredamagetoleranceisthecriticaldesignfac tie 2099 plate forging better strength modulus tor wt cu composition ranging 2 9 3 3 density corrosion performance the7075 t73 7050 respectiveoflifrom0 9 to1 1 underconstantamplitudeload t74 plate product t8e67 temper much higher strength ing stress ratio r 0 1 fatigue endurance limit almost thanthe2024 t3511or2026 t3511withbettertoughness much 40 2024 yield stress 2198 t351 8 bettercorrosionresistance fig 5 andlowerdensity thefatigue lower respective yield stress taking account crack growth resistance alloy 2099 also show improvement density 2198issuperiorto2024inhighcyclefatigueandfatigue respect 2024 t3511 baseline alloy endurancelimitregimes forthesamenormalisedappliedstresses forfatiguecriticalcomponents 47 2198 observed absorb 2 3 time energy fracture effect normal heat treatment thermomechanical than2024 50 51 comparingthefatigueresultsinairitwasob heattreatmentsonthemechanicalpropertiesandfracturetough servedthat2524 t3presentedahigherfatiguestrengthandfati nessofthe2a97newgenerational lialloywerestudiedbyyuan gue limit 2198 t851 al li alloy however et al 48 aim improve relationship strength alloy pre corroded saline environment presented ductilityandfracturetoughness andmakepossibletheirapplica similarfatiguebehaviour 52 tions aeronautical industry al li 2a97 alloy 2060and2055arethenewest3rdgenerational lialloys 2060 developed primarily attempt used plate has0 75wt ofli 3 95wt ofcuand0 85wt ofmgwhereas gings promising aerospace material stated 2055 1 15 wt li 3 7 wt cu 0 4 wt mg problemwiththisalloyisthatityieldslowductilityandfracture wt alloying element approximately toughnessint8temperwithahightensilestrength andityields thesetwoalloys thesealloysshowimprovedstrength toughness lowstrengthint6temperwithahighductilityandfracturetough relationship additionally alloy exhibit good thermal ness with4 deformationafterlowtemperatureunderaging stability both2055and2060haveexcellentcorrosionperformance ductilityandfracturetoughnesswereimprovedforthe2a97alu comparedtothatofcommonaerospacealuminiumalloyssuchas p minium lithiumalloy thek qvalueo pf43 5mpa minthet8tem 2024 t3and7075 t6 therefore thesealloyscouldbealternative per higher 42 5mpa t6 temper materialsforfuselage lowerwingandupperwingconstructions obtained byheat treatmentprocessandthermomechanicalheat trade study analysis show implementation al li alloy treatmentprocess 48 cansavesignificantweightoverthebaseline2000and7000series anothernewgenerational cu lialloy2050wasdevelopedto aluminium alloy instance fuselage skin application replace 2000 series 7000 series alloy medium 2060 t8cansave7 weightcomparedtothatof2524 t3 forlower high strength high damage tolerance needed 49 wingskinapplications2060 t8cansave14 weightcomparedto strength corrosionresistance fatigueinitiationandcrackgrowth 2024 t351 upper wing skin stringer resistancepropertieswerecomparedandaccordingtothetestre application 2055 t8 save 10 weight compared sults concluded 2050 t84 alloy addition 7055 t7751 47 53 3rd generation al li alloy offer density benefit offer improvement 2024 t351 sta 10 weightsavings lowerriskand30 lessexpensivetomanufac tic related property corrosion resistance compared ture operate repair composite intensive plane toincumbentalloy7050 t7451 the2050 t84offersanimproved addition thesealloyscanprovidepassengercomfortfeaturesthat strength toughness balance at5 lowerdensityandsignificantly equivalent composite intensive plane large table4 chemicalcompositionofsomeal lialloys 22 al lialloys li cu zn mg mn fe si cr zr ti others 2050 0 7 1 3 3 2 3 9 0 25 0 2 0 6 0 2 0 5 0 1 0 08 0 05 0 06 0 14 0 1 0 2 0 7ag 2090 1 9 2 6 2 4 3 0 0 1 0 25 0 05 0 12 0 10 0 05 0 08 0 15 0 15 2098 0 8 1 3 3 2 3 8 0 35 0 25 0 8 0 35 0 15 0 12 0 04 0 18 0 1 0 25 0 6ag 2099 1 6 2 0 2 4 3 0 0 4 1 0 0 1 0 5 0 1 0 5 0 07 0 05 0 1 0 5 0 05 0 12 0 1 0 0001be 2199 1 4 1 8 2 0 2 9 0 2 0 9 0 05 0 4 0 1 0 5 0 07 0 05 0 05 0 12 0 1 0 0001be 8090 2 2 2 7 1 0 1 6 0 25 0 6 1 3 0 10 0 30 0 20 0 10 0 04 0 16 0 1 presentedinfig 6 itisshownthatallseriesofaluminiumalloys canbefrictionstirwelded therivetingisacceptedasthetraditionaltechniqueofjoining fuselageandwingstructureswhicharegenerallymadeofalumin iumalloys however rivetingincreasestheweightoftheairframe riveting also cause stress concentration leading fatigue crack initiation growth another way joining structure welding since fuselage wing part made high strength 2000 7000 series aluminium alloy weldability ofthesealloyscanberelativelyverylow alsointraditionalweld ingtechniquesmetalisheateduntilmeltingpointwhichcausesa largeareaofheataffectedzone haz hazreducesthemechanical propertiesofthemetalsresultinginreducedstrengthandreduced resistancetofatigue thedifficultieswiththeweldingofthehigh fig 4 positioningofselectedal cu lialloysinliandcuconcentrations 34 strengthaluminiumalloyscanbelistedasfollows 1 thestablesurfaceoxidemustberemovedbyeitherchemi calmethodsorbythoroughlywirebrushingthejointarea 400 b weldcrackingordistortionduetoresidualstressesresulting 350 fromhighcoefficientofthermalexpansion c high thermal conductivity aluminium requires 300 highheatinputduringweldingfurtherleadingtothepossi 250 bilityofdistortionorcracking weld cracking due aluminium high solidification 200 shrinkage 150 e

aluminium shighsolubilityforhydrogenwheninthemol tenstateleadstoweldporosity 100 f
susceptibilityofhighstrength2000and7000seriesalloysto 50 weldcracking 0 2024 t3 7075 t6 7050 t74
2099 t86 2199 t8e80 2060 t8 aftertheinventionoffrictionstirwelding fsw in1991asan alternative way
welding research efforton application fswinaircraftmanufacturingtechnologyincreasedsubstantially
frictionstirwelding fsw isasolid stateprocessthatoperatesby window
higherhumidityandhighercabinpressure duetotheir generating frictional heat rotating tool work
improvedfatiguebehaviour accordingtothetestresultsinaddi piece rotating tool shoulder threaded pin
move tion improvement material property application along butting surface two rigidly clamped plate
placed advanced structural design concept resulted 10 time onabackingplateasshowninfig 7
theshouldermakesfirmcon improved damage tolerance performance critical area beside
tactwiththetopsurfaceoftheworkpiece heatgeneratedbyfric advantage aluminium lithium alloy fusion
welding tion shoulder softens material welded higher capacity standardised use tooling mature
assembly tech plasticdeformationonthemetaloccursasthetoolismovedalong niques repair maintenance
procedure ease recycling theweldingdirection materialistransportedfromthefrontofthe
attheendoftheaircraft slifemaketheal lialloyscompetewith tool trailing edge forged joint although polymer
composite currently used al li alloy offer fig 7showsabuttjointforillustration othertypesofjointssuch
improvement delaminationsinthesealloysplayasignificantrole
aslapjointsandfilletjointscanalsobefabricatedbyfsw 57 intheirfractureprocesses therefore
amorecompleteunderstand fswoffersseveraladvantagescomparedtotraditionalwelding
ingofthefactorsthataffectthebehaviourofthesedelaminations technique
fswprocesstakesplaceinthesolidphasebelowthe corresponding effect primary crack behaviour
meltingpointof themetals tobe joined problemsrelatedto especiallynearholesneedtobewellunderstood 45
54 solidificationofafusedmaterialareeliminated difficulttofusion
weldmaterialslikethehighstrength2000and7000seriesalumin iumalloys
couldbejoinedwithminorlossinstrength 5 developmentsinjoiningtechniques main advantage friction stir
welding listed follows aircraft manufacturer continuing research
activitiesinthefieldoftheconstructionofaircraftfuselagestruc weldingofbutt
lapandtjointconfigurationsarepossible tures increasing demand damage tolerance b
nospecialneedforjointpreparationisrequired fuselagestructures
increasedcostpressureamongaircraftmanu c 2000and7000seriesalloyscouldbewelded facturers
requirement airline lower aircraft dissimilaralloyscouldbewelded inspectionandmaintenancecosts
newtrendsintheconstruction e nocrackformationoccursduringthefusionandhazs manufacture aircraft
fuselage therefore emerged f noweldporosityoccurs whichwelding bonding
andextrusionareincreasinglyreplacing g nofillermetalsneeded theuseofrivets 55
thetrendofbuildinglargerstructureswith h foraluminiumnorequirementforshieldinggases
fewerpartshasledtodemandsforthickerandlongerplatefrom complex section machined alternatively
general mechanical property obtained fsw better smaller part joined together welding appears many
welding process example static suitable solution 13 weldability aluminium alloy
propertiesofthefrictionstirwelded2024 t351arebetween80 apm sserts dlohserht cc t 868 dursun c soutis
materialsanddesign56 2014 862 871 3rd generation al li alloy conventional aerospace al alloy fig 5
comparisonofcorrosionresistanceofal lialloyswith2000and7000series alloy thefigureisbasedon 47 53
dursun c soutis materialsanddesign56 2014 862 871 869 fig 6 weldabilityofvariousaluminiumalloys
thefigureisbasedon 56 weld research invested understand effect theseparameters 61 63 another
welding technique interest laser beam weldingofhighstrengthaluminiumalloyswhererelativelysmall
aerospaceproductionofpartsisrequired withthisweldingpro ce good weld property obtained high
production speed noelectrodeorfillermetalisrequiredandnarrowwelds withsmallhazsareproduced
laserweldingproducesaconcen tratedhighenergydensityheatsourcethatresultsinverynarrow heat
affected zone minimising distortion loss strengthinhaz 1 laser beam welding radiant energy used
produce heat required melt material joined concentrated beam coherent monochromatic light guided
optical de vice focused small spot higher power density abutting surface part joined dissimilar alloy fig 7
schematicoffsw 57 couldbejoinedinanoncontactprocess pulsedorcontinuouswave
modelasersareusedtojointhemetals themainadvantagesofla and90 oftheparentmetal
andthefatiguepropertiesapproach serweldingaretheshapeoftheweldandgoodpenetration high

thoseoftheparentmetal 1 precision high mechanical property weld high welding joint produced fsw higher strength riveted speed low heat input high flexibility possibility automa jointsandmuchlowerresidualstressesthantypicalfusionwelded tion local weld heat affected zone occur joint inwelding7000seriesaluminiumalloys postweldageingis help high energy density beam therefore good necessarytostabilisethemicrostructureinthefrictionstirwelded mechanicalpropertieswithrelativelylowdistortionofthework region theselectedoveragingtreatmentsalsoimprovecorrosion piececouldbeachieved themaindisadvantagesaretherelatively resistanceofthesealloys 58 highcostofinvestmentandtheimportantrequirementsrelatedto due high strength fsw joint allows considerable machining part assure precise groove reduced weight saving lightweight construction compared conven dimensional tolerance higher product quality term im tional joining technology use welded instead riveted provedin serviceproperties couldbeachievedthrough improved jointsisalsoadvantageousbecauseofthelowerproductioncosts tolerance accurate control process parameter selection therefore fsw process recently identified key new material product redesign eads airbus invested technologyforfuselageandwingmanufacturingbyleadingaircraft inlaserweldingasareplacementforrivetinginnon criticalappli manufacturer cation indouble sidedlaserbeamweldingoft jointstheincident asthelargeaircraftexperiencehigherstressesandshorterfati beamposition incidentbeamangle andbeamseparationdistance gue life technology applied carefully exist important welding parameter incident beam several parameter influence quality positionhasgreatimpactonjointquality 6xxxseriesal mg sial strengthofthefrictionstirweld thisprocessmustbeoptimised loys susceptible hot cracking aluminium filler foreachspecificapplication inordertooptimisetheperformance aa4047 wirecontainingexcesssiliconisrecommendedfor6xxx ofthefswjoint itisimportanttoidentifytheweldingparameters series alloy reported crack sensitivity decrease themainfswprocessparametersarethefollowings 59 60 silicon content exceeds 1 5 64 one application involves joining stiffening stringer skin fuselage dam toolgeometry shoulder probe age tolerantalloy6013isthebasematerialand4047isthefiller b clampingsystem material stringer welded two side 10m min c axialload usingtwo2 5kwco laserbeams thejointisdesignedsuchthat 2 toolrotationaldirection thehaziscontainedinthestringer anddoesnotimpingeonthe e plungedepthofprobeinworkpieces skin theprocesswasfirstusedinseriesproductionoftheairbus f plunge speed probe workpiece start 318 andwasthenimplementedsuccessfullyinotheraircraftmod position el 65 g dwelltimeatstartoftheweld h tiltangle preheating interpasstemperatureofworkpieces 6 conclusion j controlduringplunge dwellandweldperiods k weldingspeedversusrotationspeed aluminiumalloyshavebeensuccessfullyusedasprimarymate rialforthestructuralpartsofaircraftformorethan80years air asmentionedabovesincethereareseveraltoolsandoperating craft designer posse considerable experience design parametersthataffectthequalityandstrengthofthefrictionstir production operation maintenance aluminium airframe 870 dursun c soutis materialsanddesign56 2014 862 871 theinfrastructureandknowledgebasehasbecomemature itisbelievedthatdevelopmentsofadvancedhybridmaterials ever withtheintroductionofhighperformancepolymercompos like fibre metal laminate could provide additional opportunity ites application airframe design reduced role aluminium alloy new material option airframe aluminiumalloysuptosomeextentduecomposites highspecific industry property reduced weight fatigue performance corrosion resistance boeing787 airbusa350 inorderforaluminiumalloys reference toremainattractiveintheairframeconstructionandcompetewith orbecompatiblewithcurrentlyusedpolymercomposites 1 campbell fc manufacturing technology aerospace structural search activity improvement structural performance material 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unlikemostconventionalaerospace 22 meratia materialsreplacementforagingaircraft rto ag avt 140 chapter alloy fusion weldability al cu li alloy could introduce 24 newopportunitiesinthefabricationoffuselage therefore inaddi 23 verma bb atkinson jd kumar study fatigue behaviour 7475 aluminiumalloy bullmatersci2001 24 231 6 tiontometallurgicaldevelopmentswiththecombinationofother 24 smithb theboeing777 advmaterprocesses2003 41 4 manufacturing technique riveting help reach opti 25 chenyq pansp zhoumz yidq xudz xuy effectsofinclusions grain miseddamagetolerantdesigns boundary grain orientation fatigue crack initiation propagationbehaviorof2524 t3alalloy materscienga2013 580 150 8 highstrain ratesuperplasticformingandcastingarealsodraw 26 zhengzq caib zhait lisc thebehavioroffatiguecrackinitiationand ing attention cost effective solution advanced joining tech propagationinaa2524 t34alloy materscienga2011 528 2017 22 niqueswillalsomakealuminiumstructuresmoreaffordable 27 nec cid 2 sulescu da 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life aa2024 tions thereshouldbenoreductiononthelevelsofsafetythatis specimen materdes2014 54 212 21 alreadyreachedwithconventionalalloys fatigueresistance cor 32 shi h han eh liu f kallip protection 2024 t3 aluminium alloy corrosion resistant phytic acid conversion coating appl surf sci rosion resistance damage tolerance important 2013 280 325 31 mechanical property airframe material affect 33 kim st tadjiev yang ht fatigue life prediction random loading inspection maintenance repair cost mod conditionsin7475 t7351aluminumalloyusingthermsmodel intjdamage mech2006 15 89 102 ern aluminium alloy could compete effectively polymer 34 warner recently developed aluminium solution aerospace composite application matersciforum2006 519 521 1271 8 dursun c soutis materialsanddesign56 2014 862 871 871 35 chen chenk pengg jial dongp effectofheattreatmentonstrength 50 alexopoulosnd migklise stylianosa myriounisdp fatiguebehaviorofthe exfoliationcorrosionandelectrochemicalbehaviorof7085aluminumalloy 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Top Keywords

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