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metal review advancement 7xxx series aluminum alloy aircraft structure review bozhou boliu andshengenzhang instituteforadvancedmaterialsandtechnology universityofscienceandtechnologybeijing beijing100083 china b20170572 x ustb edu cn correspondence liubo ustb edu cn b l zhangshengen mater ustb edu cn z abstract 7xxxseriesaluminumalloys al7xxxalloys arewidelyusedinbearingcomponents suchasaircraftframe sparsandstringers fortheirhighspecificstrength highspecificstiffness high toughness excellentprocessing andweldingperformance therefore al7xxxalloysarethemost importantstructuralmaterialsinaviation inthispresentreview thedevelopmenttendencyandthe mainapplicationsofal7xxxalloysforaircraftstructuresareintroduced andtheexistingproblems aresimplydiscussed also theheattreatmentprocessesforimprovingthepropertiesarecompared andanalyzed itisthemostimportantmeasuresthatoptimizingalloycompositionandimproving heattreatmentprocessaretoenhancethecomprehensivepropertiesofal7xxxalloys amongthe method 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whichisdemonstratedinfigure1 inaddition copyright 2021 author approximately20 690low fuel efficientpassengerandcargoaircraftswillbereplacedby licensee mdpi basel switzerland new 6 7 rapid development aviation industry contributes progress article open access article ofnewmaterials althoughtheproportionoftitaniumalloysandcompositematerials distributed term hasincreasedinnewlydevelopedaircraft theuseofhigh strengthaluminumalloysstill conditionsofthecreativecommons accountsforalargeproportion whichmakesitindispensableintheaerospacefield 8 attribution ccby license http creativecommons org license 4 0 metals2021 11 718 http doi org 10 3390 met11050718 http www mdpi com journal metalsmetals 2021 11 x peer review 2 30 alloy still account large proportion make indispensable aerospace metals2021 11 718 2of29 field 8 50 000 22 420 40 000 0 30 000 25 900 20 000 10 000 5210 0 2019 2039e figure 1 boeing forecast global aircraft demand 6 shown figure 2a aircraft structural material shown steady 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manonrueatlh aavner4a0g0e tohfo muosaren dthatonn 4s0f0r othmou2s0a1n6d to2020 ton 2016 2020 civil aircraft type aluminium alloy steel titanium alloy composite material others senalp fo rebmun year inventory substitute increment 100 80 60 40 20 0 egatnecrep metal 2021 11 x peer review 3 30 civil aircraft type aluminium alloy steel titanium alloy composite material others 100 80 60 40 20 0 figure 2 ratio material used aircraft civil b military 9 traditional aluminum alloy aircraft structure principally high strength al 2xxx alloy 2024 2224 2324 2424 2524 etc ultra high strength al 7xxx alloy 7075 7475 7050 7150 7055 7085 etc 10 1980s new material including aluminum lithium alloy rapid solidification aluminum alloy aluminum matrix composite material rapidly developed 11 12 traditional 2xxx series al 7xxx alloy material greatly affected still show strong vitality superior performance 13 16 according statistic high performance 2xxx series al 7xxx alloy still mostly used 70 structural 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mactoermiaplso switeerme agtreeraitallys ahfafvecetebde e nburta pthidelyy sdtielvl eslhoopwed st r1o1n 1g2 v ittahlietyt raditional 2xxx series superior perfaonrmdaanlc7ex x13x a1l6l amccaoterdriianlgs wtoe srteagtirsetaictsly haifgfehc tpeedr fborumttahnecye s2txillxsxh owstrongvitalitywith series al 7xxx allotyhse iarrseu spteilrli omropsetrlyfo urmseadn cine m13o r1e6 h aanc c7o0r isntgrutcotustraatli smticast erhiiaglhs opfe rformance2xxxseries aircraft according tahned aappll7ixcaxtxional lcolaysssaifriecasttiiollnm aovstilaytiuosne daluinmminouremt hcaann 7b0e dsitvriudcetdu ralmaterialsofaircraft casting aluminum aacllcooyr einxgtrtuodtehde aalpupmliicnautimon aclllaosys fircoallteiodn lauvmiaitniounma laulmloiyn ufmorgcaend bedividedintocasting aluminum alloy etc 17a lu tmhien aulmumalilnouym e xptrroupdoedrtiaolnuaml idniusmtribaullotiyo nr ofollre davailautmioinn uism shaollwoyn forgedaluminumalloy figure 3 etc 17 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thermaldeformationlikerolling extrusion solidsolution quenching andagingtreatment 20 21 thispaperreviewsthedevelopmenttendency requirementstage mainbandsand application joiningandmillingtechniques andadditivemanufacturingtechnologyofal 7xxxalloysforaircraftstructures andthemainproblemsfacedintheapplicationsare pointedout furthermore themainmeasurestoimprovetheperformancearediscussed mainlyintroducingtheeffectsofsolution quenchingandagingprocessesontheproperties moreover thedevelopmentdirectiontothenewgenerationofal7xxxalloysforaircraft structureandthecorrosionpredictionarediscussed 2 developmentofal7xxxalloysforaircraftstructures 2 1 developmenttendency from1923to1924 germanscientistssanderandmeissneretal 22 discoveredthat theal mg znalloyformedmgzn strengtheningphaseaftersolidsolution quenching 2 andagingtreatment whichgreatlyimprovedthestrength sincethen researchonal7xxx alloyshasbegun in1932 webberetal foundthatasmallamountofcuandmnelementsmetals2021 11 718 4of29 containedinal mg 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alcoalaunchedanewgenerationofhigh strengthandhigh toughnessal 7085 alloy due good casting property excellent hardenability great application potential new generation aircraft component reported thecomprehensivepropertiesofal7085alloyhasexceededal7050alloy atthesame process thestresscorrosionresistanceandfracturetoughnessofal7085alloycomponent areequivalenttoal7050alloy butitsstrengthcanbeincreasedby15 anditsmaximum thicknessisupto305mm untilnow al7085alloyisoneofthemostadvancedaluminum alloysintheworld 3 18 25 27 29 inshort thedevelopmentlawofal7xxxalloysisbasedontheexistingproperties greatly improve aspect alloy specifically term alloy design contentofimpuritiessuchasfeandsiisgettinglower andthealloyingdegreeisgettingmetals 2021 11 x peer review 5 30 1989 alcoa developed t77 treatment process applied 7150 alloy obtain t6 state strength t73 state corrosion resistance strength al 7055 alloy t77 aging higher 1992 japanese sumitomo light metal co ltd produced ultra high strength aluminum 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require ments aircraft material shown figure 6 25 35 38 figure6 performancerequirementsoftheaircraftmaterials 25 35 38 39 adaptedwithpermission figufrreo m6 rpeefr f o3r5m acnocpe yrreiqguhitr1em99e6netsls oefv itehre aircraft material 25 35 38 39 adapted permis sion ref 35 copyright 1996 elsevier themainfeaturesandapplicationsofal7xxxalloysareshownintable2 itcanbe setehne tmhaatina lfe7a0t7u5reasl loanyds aarpepmliacaintiloynuss oedf afol r7fxuxsexla aglelobyusl karhee asdhso wwni ning utpabpleer 2 k iint sc awn ing suepenp etrhpata naell s7 0a7n5d avlelortyisc aalrtea imls aainlly74 u7s5eadl lofoyri sfumsealianglye ubsueldkhfoeradwsi n wgisnkgin u papelr7 0s5k0inasl l oys winagr eumppaeinr lypaunseelds nanthde vfuersteilcaagle tbauillsk haela d7s4 7a5 la7l0lo5y5 aisll omyasianrley muasiendly four ewdifnogr lsoknignsf u saell age 7050s tarlilnogyesr sa rfeu msealaingleyb uesaemds na tnhde ffuusseellaaggeeu bpuplkerhestardinsg aerls 70a5l57 a0l8l5oyasll aoryes maraeinmlyai unlsyedu sfeodr longw fiunsgelsapgaer sstarnindgreirbss fuselage beam fuselage upper stringer al 7085 alloy mainly used wing spar rib table2 mainfeaturesandapplicationsofal7xxxalloys 28 40 42 alloy mainfeatures mainproductsandstatus mainapplications t6t73t76sheetplate t651t7651t7351 highstrengthatlowtemperature poor upperandlowerwingsskins 7075 thickplate t6t73t7352casting t6511 weldability poorsccresistance stringer frame t3511extrusion insteadof7079 highstrength goodscc t3511t76511extrusion t73t7352forgings 7049 mainlandinggear resistance t73sheetandthickplate goodstrength goodsccresistance better t73t74t7452forgings t7351t76511 7149 mainlandinggear fracturetoughnessthan7049 extrusion t73t74t7452forgings t7351t76511 7249 bettercomprehensivepropertiesthan7149 mainlandinggear extrusion 7175 highstrength goodcorrosionresistance t66t74t7452forgings t74t6511extrusion spar mainlandinggear highstrength highfracturetoughness t61t761sheetplate t651t7351sheetand fuselageskins wingskins central 7475 goodfatigueresistance goodcorrosion thickplate wingstructures spar bulkhead resistance highstrength goodfracturetoughness t651t7451thickplate t3511t76511t73511 fuselageframe wingskins 7050 goodsccresistance goodexcoresistance t74511extrusion t7452t76t7652t74 bulkhead stringer stiffener poorhardeningsensitivity forging t73wire t76sheetplate upperwingstructures fixed highstrength goodcorrosionresistance t651t7751thickplate t6511t77511 leadingedge upperwing 7150 goodfatigueresistance extrusion t77forgings stringer fuselagereinforcement skeleton seattracks highercompressivestrengthandtensile upperwingskins stringer t7751thickplate t77511extrusion t77 7055 strengththan7150 similarfracture horizontalstabilizer skeleton forging toughnessandcorrosionresistanceto7150 seattracks cargotracks goodcomprehensiveproperties high 7085 hardening highstrength highfracture t7651thickplate t7452forgings wingsparsandstringersfora380 toughness goodsccandexcoresistancemetals2021 11 718 8of29 2 4 joiningandmillingtechniques large number high precision connecting hole need processed fasten thedissimilarstacksofthefuselagetogetherwithboltsandrivetsintheaircraftassembly process whereasinfuselagemanufacturing thedrillingoperationsofdissimilarstack materialsarecrucial 43 traditionaldrillingwillcauseseveraldefectssuchasdelami nation tearandburr sothatthemachiningaccuracyisdifficulttoguarantee therefore thedrilling studieshavebeenarousedbymany scholar mainlyincludingdrillingde fectresearch tooloptimization drillingparameteroptimization andvibrationassisted drillingtechnology denkena et al 44 applied helical milling technology drilling cfrp titaniumlayercompoundsandstudiedtheinfluenceofdifferentprocessparameterson theprocessingquality zitouneetal 45 foundthatlongermetalchipsleadtoadecrease inthesurfacequalityofthecompositemateriallayer spore andgoodbrokenchipscan improveholequalityandextendtoollife wangetal 46 studiedthetoolwearduring drillingexperimentsonstackofcarbonfiberreinforcedplasticandtial6v4andfoundthat thedifferentwearmechanismsofthetwomaterialscausedthedrillstoweartooquickly brehlanddowetal 47 studiedthekinematicrelationshipsof1d linearvibratorytool path and2dvam circular ellipticaltoolpath vibration assistedmachining andfound thattheintermittentcontactbetweenthetoolandtheuncutmaterialworkpiecereduces frictionandheating andimprovessurfacequalityandmachiningaccuracy sothatextends toollife lacalleetal 43 analyzedandmodeledthechipformationprocessofdrilling assistedbylow frequencyvibrationsoffc alstackmaterial andfoundthattheproblems forthefinalgeometricalqualityoftheholeandburrformationcanbeavoidedbythechip segmentationduringthedrillingoperationresultinginlesstemperatureincreasing however rivetingincreasestheweightofthefuselageandalsocausesstressconcen trationwhichleadstofatiguecrackinitiationandgrowth inordertoreducetheweight andtheinspectionandmaintenancecostsfortheaircrafts newtrendsintheconstruction andmanufactureofaircraftfuselagehavethereforeemergedinwhichfriction stirwelding laserbeamwelding andmillingmachiningareincreasinglyreplacingtheuseofboltsand rivet 2 48 inordertoachievethepurposeoflightweightandmeettherequirementsofaircraft performance manyskeletonparts especiallymainload bearingstructuralparts suchas aircraftbeams bulkhead andwallpanels aregenerallyprocessedintocomplexgrooves rib boss lighteningholes andotherintegralstructuralpartsthataredirectlyhollowed large block blank therefore aviation integral structural part characteristic complex structure large size high material removal rate many thin walledstructuralpartslikeframes cantileverbeams andwallpanels 49 due poor rigidity thin structural part affected factor cutting force cutting heat cutting chatter part cutter relieving milling therefore prone deformation seriously affect dimensional accuracy structurefunction themainformsofthinstructuralpartdeformationaremachiningvibrationdefor mation cutterrelievingdeformation andoverallmachiningdeformation whereasthe factorsthataffecttheoverallmachiningdeformationaremainlythematerialpropertiesof theworkpiece tongslayoutdesign processparameters toolpathstrategies etc in1997 tlustyetal 50 proposedatoolpathoptimizationschemeforthin walled partdeformationbyeffectivelyutilizingtheunprocessedpartofthecomponentsassupport soastomakefulluseoftheintegralrigidityofthecomponents in2004 ratchevetal 51 establishedtheanalyticalflexibleforcemodelconsidering thegeometriccharacteristics theimmersionangleandthematerialpropertiesofthetool combinedwiththefiniteelementtechnology theyputforwardthestaticmachiningerror compensation model low rigidity component providing guidance nc verificationtechniques metals2021 11 718 9of29 in2005 herranzetal 49 proposedanapproachfortherightselectionofcutting condition high speed milling low rigidity part avoid static dynamic problem localandglobalstructuredeformations andvibration ithasbeenappliedin theactualproductionprocess andtheunrecoveredpartshavebeenreducedby20 26 ascalculated 2008 jitender et al 52 developed milling simulation system based finite element thesystemcanpredictthepartthinwalldeflectionsandelasticplasticdefor mations machining considering effect fixturing operation sequence toolpath andcuttingparametersontransientthermalloadingconditions thenumerical simulationresultsofcuttingforceanddeformationobtainedareingoodagreementwith theexperimentaldata 2016 ismail et al 53 established functional relationship chanicalandthermalloadsontheworkpieceandthemachiningparameterstoapplythe combinedeffecttothethinpartandproposedanewmulti physicsbasedfiniteelement modeling fem approach predict thin part deformation micromilling simu lationresultsareverifiedbyreal timelasermeasurementandwhitelightinterferometer measurementwiththeaverage14 error in2019 lietal 54 constructedasemi analyticalmodelconsideringbiaxialblank residualstresstopredictmachiningdeformationsoffivethin walledpartswithdifferent stiffening rib layout accuracy model verified fem simulation andmachiningexperiments theresultsshowthatthemachiningdeformationdecreases withtheincreaseofequivalentbendingstiffnessinthelengthdirection andtheequivalent stiffnessinthewidthdirectionhaslittleeffectontheoverallmachiningdeformation 2 5 additivemanufacturingtechnology due excellent strength weight stiffness weight ratio good machinability al 7xxx alloy widely applied manufacturing structural compo nentsintheaerospaceindustry intraditionalsubtractivemanufacturingprocesses geometricalcomplexityofmanyaerospacecomponentsboughtmanydifficulties however additivemanufacturing processesarewidelyusedinthisfieldbecauseofthesmall size highvalue andgeometricalcomplexityforthecomponentsduringthemanufacturing process furthermore throughdesigningandmanufacturingthecomponentswithcom plextopologies amprocessesreducethetotalnumberoftheaircraftpartstoenablepart consolidation 55 thepartconsolidationbringsmanybenefitsincludinglowerproduction cost componentfailurerisk betterproductpropertieslikehighstrength weightratio andlightweight andlowermaterialusagewithpartcomplexityincreasing therefore massamedcomponentshavebeenadoptedtotheaerospaceindustry 56 process also known 3d printing produce complex geometrical com ponentslayerbylayeronthebasisofthree dimensional 3d dataobtainedbyscanning physicalobjectsorusingdesignsoftware therepresentativesofamtechnologiesinclude selectivelasersintering sl selectivelasermelting slm lasernearnetshaping lens electronbeammelting ebm wirearcadditivemanufacturing waam 57 in1995 thefraunhoferlasertechnologyinstituteingermanyfirstcarriedoutselec tivelasermelting slm formingtechnologyresearch 58 thistechnologydirectlymelts metalpowderbyselectingappropriateprocessparameterstoobtaincomponentswithhigh density itshowsthataluminumalloysareeasytooxidize andhavehighreflectivityto laser sothatslmformingismoredifficult in2011 bartkowiaketal 59 tooktheleadindevelopingslmformingresearchof high strength aluminum alloy research slm forming feasibility al cu al znpowderbylowpowerfiberlaser sincethen theresearchonslmformingofhigh strengthaluminumalloyhasattractedtheattentionoftheindustryanddevelopedrapidly inrecentyears atpresent theresearchonslmformingofhigh strengthaluminumalloysmainly focus al cu alloy al zn mg cu alloy compared al si alloy al cumetals2021 11 718 10of29 alloy al zn mg cu alloy difficult form slm due wider solidification interval greater hot cracking tendency higher thermal conductivity higheralloyelementcontent higherlaserenergyisrequiredduringtheformingprocess anditiseasytocauseelementburningloss sotheadditivemanufacturingtechnologyof high strengthaluminumalloysdevelopsslowly 57 in2016 kaufmannetal 60 studiedtheinfluenceofslmprocessparametersonthe formingqualityofal7075alloy andfinallyobtainedasamplewithadensitygreaterthan 99 byoptimizingtheparameters however apreheatingtemperatureofupto200 cdid notshowasignificantpositiveeffectonreductionofhotcracks 2016 sistiaga et al 61 added 4 wt silicon al 7075 alloy powder

increasedthedensityofslmprocessedaluminumalloyto99 andthehardnessto171hv reaching conventional 7075 hardness level treated t6 study show
crackscanbeavoidedandmechanicalpropertiescanbeimprovedbyaddingappropriate alloyingelements metal 2021 11 x peer review 11 30 in2017 singhetal 62 addednickeltoal7050alloypowdersediments andthebrittle a1 niintermetallicwasformedduetonisegregationatthedendriticboundary resulting 3 inpoortensileductilityofal7050alloy laserdepositedsamplesbyfrictionstirprocessed 178 mpa 302 mpa nfdsp 6 h reeasp1enctiipvaerltyic lmesoinreαo vae1rm aafttreixr afrsepre fihneeadt atrnedatumniefonrtm tlhyed istributed theyield 3 strength elongation are tirnecnrgetahs etedn sbilye astbroenugtt 1h0 n elongationofthealuminumalloyareupto178mpa 302mpa and6 respectively moreover afterfspheattreatment thestrengthandelongationare 2017 martin et al 63 published high performance slm forming method increasedbyabout10 7xxx series ultra high strength aluminum alloy tensile strength yield strength in2017 martinetal 63 publishedahigh performanceslmformingmethodfor elongation formed al 7050 alloy sample t6 heat treatment 383 417 7xxxseriesultra high strengthaluminumalloys thetensilestrength yieldstrengthand mpa 325 373 mpa 3 8 5 4 respectively elongationoftheformedal7050alloysamplesaftert6heattreatmentare383 417mpa 325 373mpa and3 8 5 4 respectively 3 main problem al 7xxx alloy aircraft structure 3
mainproblemsofal7xxxalloysforaircraftstructures 3 1 performance problem 3 1 performanceproblems due combined effect service environment bearing load
duetothecombinedeffectoftheserviceenvironmentandthebearingloadduring actual use stress corrosion always fatal defect al 7xxx alloy air actualuse
thestresscorrosionhasalwaysbeenafataldefectofal7xxxalloysasaircraft craft structural material caused many aircraft accident thus greatly limit structuralmaterials whichhascausedmanyaircraftaccidents thusgreatlylimitingthe ing application 19 64 papcliccoartidoinnsg 1t9o 6t4h e alictceorradtuinrge oththe emliateirna tsutrree stsh ceomrraoinsisotnre scsraccokrr osioncracking scc ing scc mechanism aml 7ecxhxaxni samlloinysa ils7 xanxoxdailcl odyississoalunotidoinc daissssiosltuetdio cnraascskisintegd chryacdkrion g hydrogeninduced gen induced cracking cpraascskiivneg failnmd rpuapsstiuvreefi lam rsuhpotwurne ians fsihgouwrne i7n f6i5g u re7 65 figure 7 illustration mechanism scc aluminum alloy anodic dissolution assisted figure7 illustrationofmechanismsofsccforaluminumalloys anodicdissolutionassisted cracking b hydrogen induced cracking c passive film rupture reprinted permission cracking b hydrogeninducedcracking c passivefilmrupture reprintedwithpermissionfrom ref 65 copyright 2016 elsevier ref 65 copyright2016elsevier anodic dissolution assisted cracking mechanism shown figure 7a typi cal intergranular corrosion failure mode grain boundary grain adjacent region anodic rest microstructure anodic dissolution proceed selectively along boundary hydrogen induced cracking mechanism shown figure 7b cathode reduction reaction occurs alloy generate hydrogen atom hydrogen atom diffuse alloy interior hydrogen atom supersaturated alloy combine form h micro 2 scopic defect h concentration increase hydrogen pressure rise 2 stress generated hydrogen pressure higher yield strength alu minum alloy generated partial plastic deformation surface bulge form hydrogen bubble cause internal crack passive film rupture mechanism shown figure 7c oxide film surface aluminum alloy certain protective effect matrix however oxide film damaged cl rich atmospheric environment causing localized corrosion process like pitting addition due high alloy element content al 7xxx alloy formed high density precipitated phase enriched chain like manner grain boundary resulting significant alloy cracking lead stress corrosion reduces service life component 66 68 3 2 corrosion prediction environmental research service aircraft found structural part aircraft different position corrosion environment bemetals2021 11 718 11of29
anodicdissolutionassistedcrackingmechanismisshowninfigure7a itisatypical
intergranularcorrosionfailuremode whenthegrainboundariesorgrainadjacentregions
areanodicagainsttotherestofthemicrostructure theanodicdissolutioncanproceed selectively along boundary hydrogen induced cracking mechanism shown figure7b
thecathodereductionreactionoccursinthealloytogeneratethehydrogen atom
andsomeofthehydrogenatomsdiffusetothealloyinterior whenthehydrogen
atomsaresupersaturatedinthealloy theywillcombinetoformh atmicroscopicdefects 2 ash
concentrationincreases thehydrogenpressurerises whenthestressgeneratedby 2
thehydrogenpressureishigherthantheyieldstrengthofthealuminumalloy itwillbe

generatedpartialplasticdeformationsothatthesurfacebulgestoformhydrogenbubbles whichcausesinternalcracks passivefilmrupturemechanismisshowninfigure7c isanoxidefilmonthesurfaceofthealuminumalloy whichhasacertainprotectiveeffecton thematrix however theoxidefilmcanbedamagedincl richatmosphericenvironment causinglocalizedcorrosionprocesseslikepitting inaddition duetothehighalloyelement contentofal7xxxalloys theformedhigh densityprecipitatedphasesareenrichedina chain likemanneratthegrainboundaries resultinginsignificantalloycracking leadstostresscorrosionandreducestheservicelifeofthecomponents 66 68 3 2 corrosionprediction theenvironmentalresearchduringtheserviceoftheaircraftfoundthatwhilethe structural part aircraft different position corrosion environment different sothatthecorrosiontypesandcorrosionmechanismswillbedifferent fore corrosion behavior al 7xxx alloy aircraft structure complicatedengineeringphenomenon butalsoamultidisciplinaryscientificproblem hasbecome anurgent problemthat howtoconstruct areasonable predictionmodel accuratelypredictthecorrosionbehaviorofal7xxxalloysforaircraftstructures withtheapplicationofcomputersandthedevelopmentofsolutionelectrochemical measurement technology series prediction model developed accurately predictthecorrosionbehaviorofal7xxxalloysforaircraftstructures atpresent common prediction model based corrosion electrochemical principle 1964 fleck 69 usedthefinitedifferencemethod fdm forthefirsttimetoevaluatethe currentdensitydistributionoftheelectrodesystem atthesametime klingertetal 70 also explored current density distribution electrode system via high speed computer attheendofthe1970s alkireetal 71 obtainedthesecondarypotentialfield distributionintheelectrolysiscellthroughfiniteelementmethod fem andpredictedthe changeofelectrodeshape afterwards corrosionpredictionwasappliedtothefieldof cathodicprotectionformarinestructures andengineeringapplicationsweregradually realized althoughthefdmandfemmethodgaverelativelyaccurateresultsinmany practicalapplications somecomplexstructures andinfinitedomainproblemscouldnotbe handled duetothelimitationofthecalculationlevelatthattime fuandchowintroduced themoreefficientboundaryelementmethod bem intothecorrosiveelectricnumerical calculationfieldfirstandprovedtheaccuracyofthismethod helleetal 72 usedand comparedtwonumericalmethodswhensolvingthegalvaniccorrosionproblemofships propeller seawater zamani et al 73 completed numerical simulation canadianwarship scathodicprotectionsystemthroughtheboundaryelementmethod comparisonofnumericalanalysismethodsareshownintable3 metals2021 11 718 12of29 table3 comparisonofnumericalanalysismethods 74 84 finiteelementmethod finitedifference boundaryelement predictionmodels fem method fdm method bem precisionofsolution approximatesolution precisiondeterminedbygridpartition applicablegeometry solvingcomplexgeometryproblems methodofsolving determinedbythedataofalargenumberofnodes voltage methodofsolving calculatedbythevoltagevaluewiththesame calculateddirectlyby currentdensity accuracy thedataattheboundary knownpotentialattheboundary knowncurrentdensityattheboundary boundaryconditions knownfunctionofpotentialandcurrentdensityattheboundary uniform heterogeneouscontinuity boundedand uniformand electrolytecharacteristic conductive continuouslyconductive solutiondomain finitefield infinitedomain thesamenumberasnodesthataredistributedon thesamenumberas numberofequations theentiredomain nodesattheboundary thetheoryandtechnologyfornumericalsimulationandpredictionofcorrosionare becomingmoreandmoreadvancedwithalargenumberofresearchers relatedscientific researchinstituteshavesuccessivelydevelopedaseriesofcorrosionprotectionprediction anddesignsoftware suchastheboundaryelementsoftwarelikeprocatandbeasy andthefiniteelementsoftwarelikeelsycacorrosionmasterandcomsol etc whilethe numericalsimulationsoftwarerelatedtocathodicprotectionhasalsobeendevelopedby beijinguniversityofscienceandtechnology theaccuracyofthecorrosionprediction resultsiscloselyrelatedtotheboundaryconditionsofthenumericalmodel whichgenerally meanstherelationshipbetweenthepotentialandcurrentdensityofthecorrosionelectrode system strommenetal 85 gavethreetypesofboundaryconditionswhencalculating cathodic protection offshore platform namely constant current density linear polarizationcurve andnonlinearpolarizationcurve thenonlinearpolarizationcurve undoubtedlyincreasesthedifficultyofcalculation butitisthemostrepresentativeand morecommon therefore iwataetal 86 proposedapiecewiselinearizationmethodto solvethisproblemwhichacceptedandquotedbyotherresearchers advancement electrochemical theory measurement technology thinelectrolytefilm thecorrosionpredictionofaviationstructuralmaterialshasaroused new research upsurge 2009 peratta et al 87 introduced galvanic corrosion modelingoftypicalmacrostructuresinaircraftattheeuropeancorrosioncongress thismeans theyprovedthattheexperimentallymeasuredpotentialdistributionandtotal galvaniccurrentarehighlyconsistentwiththecalculationresultsoftheboundaryelement shietal 88 modeledandevaluatedthegalvanicinteractionbetweenal7075alloyand noble potential material targeting model geometry noble potential material type andsolutioncompositionasinfluences itshowsthatthegalvanicactiongreatlyaffected initiation expansion localize corrosion aluminum alloy thebault et al 89 usedthefiniteelementmethodtosimulatethecu znbimetalcorrosionunderthethin electrolytefilm takingintoaccountthetransferofo intheelectrolyte themodelcalcu 2 latedcurrentdensityintheelectrodeedgebythescanningvibratingelectrodetechnique svet whichbasicallymatchesthecalculatedvalue mizunoetal 90 simulatedthegal vaniccorrosionbehaviorofal5083alloyandaisi4340steelinatmosphericenvironment andpredictedtheinter granularcorrosiondamageofal5083alloycausedbygalvanic interaction crossetal 91 usedatime dependentfiniteelementmodeltostudygalvanic corrosionbetweenaluminumandzinccoatingsonsteelsurfaces metals2021 11 718 13of29 althoughthecorrosionpredictiontechnologyofal7xxxalloyusedinaircraftstruc tureisbecomingmoreperfect thereareseveralquestionsremainedtobesolved suchas howtodeterminethecorrosiveenvironmentonthesurfaceofaircraftstructures howtoac curatelymeasuretheelectrochemicalpropertiesofmaterialsinatmosphericenvironments andhowtoselectthecorrosionpredictionmodel 92 96 first thedeterminationofthecorrosionenvironmentonthesurfaceofaircraftstruc turesisthebasisofthecorrosionprediction theaircraftstructuresarecomplexandthe corrosion environment changeable corrosion medium structure surface canbesimplydividedintosolutionandthinelectrolytefilmonlyaccordingtodifferent positionsinmanystudies itisnecessarytocarryoutfurtherresearchonthecausesofthin electrolytefilmandtheinfluencingfactorsofelectrolytefilmthickness inaddition corrosivemediumisexistedinalargenumberofcracksintheaircraftstructure formsanoxygenconcentrationdifferencecell theeffectofthisfactorontheelectrolyte filmthicknessalsoneedstobelucubrated foranother accurateandreliableelectrochem icalmeasurementdataistheguaranteeofthecorrosionprediction atpresent solution electrochemicalmeasurementtechnologyisrelativelymature nevertheless therearetwo problemsinthemeasurementofelectrochemicalperformanceofthinelectrolytefilm theonehand thechangeoftheelectrolytefilmstateaffectstheelectrodereactionmass transferprocess ontheotherhand itisdifficulttomaintainstabilityofelectrolytefilm thicknesssothatitinfluencestheaccuracyinthemeasurement furthersystematicstudy isneededfortheinfluenceofmarineatmosphericenvironmentalfactors includingcl concentration temperature andph moreover theselectionoftheappropriatecorrosion predictionmodelisavitalprocessofthecorrosionprediction asteady statecorrosion fieldcanbeusedtomodelforgalvaniccorrosionoftypicalmacrostructuresinsolution orthinelectrolytefilm whereasthecorrosionmediumchangescontinuouslywithtime forthecorrosionthatoccursinnarrowcracks sothatitisnolongerappropriatetomodel steady state corrosion field present study transient predictionofcrackingcorrosioninaircraftstructures andfurtherresearchisneededonthe quantitativeanalysisofcorrosionprocessandinfluencingfactors 4 mainmeasurestoimprovetheperformanceofal7xxxalloysfor aircraftstructures thepurposeofheattreatmentforal7xxxalloysistooptimizethethreemicrostruc ture parameter matrix precipitate mpt grain boundary precipitate gbps precipitate freezone pfz sothatthealloyshavegoodcomprehensiveproperties heattreatmentprocessofal7xxxalloysmainlyincludeshomogenization solidsolution quenching andaging themicrostructureevolutionofal7xxxalloysisshowninfigure8 atdifferentheattreatmentstages itcanbeseenthatfromtheas caststatetotheuniform annealedstate thesphericalintra granularnon equilibriumeutecticphaseandanetwork coarse non equilibrium eutectic phase grain boundary basically dissolvedintothealuminummatrixtoformasupersaturatedsolidsolution withonly small amount impurity phase remained uniform annealed state thefinalstate alargenumberoftinyanddiffuseneedle likeandsphericalparticlesare precipitatedwithinthegrains andthegrainboundaryprecipitatesaredistributedinchains alongthegrainboundaries 20 21 97 98 wemainlydiscusstheeffectsofsolidsolution quenching andagingonthemicrostructureandpropertiesofal7xxxalloys metal 2021 11 x peer review 14 30 4 main measure improve performance al 7xxx alloy aircraft struc tures purpose heat treatment al 7xxx alloy optimize three micro structure parameter matrix precipitate mpt grain boundary precipitate gbps precipitate free zone pfz alloy good comprehensive property heat treatment process al 7xxx alloy mainly includes homogenization solid solution quenching aging microstructure evolution al 7xxx alloy shown figure 8 different heat treatment stage seen cast state uniform annealed state spherical intra granular non equilibrium eutectic phase network coarse non equilibrium eutectic phase grain boundary basically dissolved aluminum matrix form supersaturated solid solution small amount impurity phase remained uniform annealed state final state large number tiny diffuse needle like spherical parti cles precipitated within grain grain boundary precipitate distrib uted chain along grain boundary 20 21 97 98 mainly discus effect metals2021 11 718 14of29 solid solution quenching aging microstructure property al 7xxx alloy figure8 microstrufcitguureree 8v mluitcioronstorfuactlu7rxe xevxoalulltoiyosn o9f7 9l8 7 xxx alloy 97 98 4 1 solidsolution 4 1 solid solution solidsolutionisthebasisoftheheat treatedstrengtheningaluminumalloystoobtain solid solution basis heat treated strengthening aluminum alloy ob highstrength itaimstofullydissolvethesolubleelementsinthealloyintothealuminum tain high strength aim fully dissolve soluble element alloy matrixtoformanearlyuniformlydistributedsupersaturatedsolution whichfacilitate aluminum matrix form nearly uniformly distributed supersaturated solution subsequentagingprecipitationtostrengthenthealloy thebasicoperationsofthesolution facilitate subsequent aging precipitation strengthen alloy basic operation treatmentareheatingandholding thesolutiontemperatureandholdingtimearethe solution treatment heating holding solution temperature holding two important parameter determine effect solution solution time two important parameter determine effect solution temperatureishigherandtheholdingtimeislonger thediffusionofsoluteatomsisthe solution temperature higher holding time longer diffusion solute morefavorable sothatthealloyelementsaremorefullydissolvedandtheagingeffectis atom favorable alloy element fully dissolved better however therecrystallizationfractionwillbeincreasedbyhightemperature aging effect better however recrystallization fraction increased high long termholdingwhichwilladverselyaffectthestrength fracturetoughness andstress temperature long term holding adversely affect strength fracture corrosionresistanceafteraging therefore agoodsolidsolutionregimeshouldbeableto toughness stress corrosion resistance aging therefore good solid solution dissolvethesolublesecondphaseasmuchaspossibleintothealuminummatrixwithout regime able dissolve soluble second phase much possible significantlyincreasingtherecrystallizationfractioninthealloy 99 aluminum matrix without significantly increasing recrystallization fraction al solid solution regime al 7xxx alloy developed single stage loy 99 multi stage solid solution single stage solid solution shown figure 9a refers enhancingthesolidsolutioneffectofthealloyelementbysimplyincreasingthefinalsolid solutiontemperatureandextendingthesolidsolutiontimeontheconditionofavoiding burning thedisadvantageofthismethodisthatthesolidsolutiondegreeofalloy ingelementsandtherecrystallizationfractionofthealloyincreasesimultaneouslywith increase solution temperature time comprehensive property ageingarepoor 100 somescholarshaveproposedastepwisetemperature increasing solutiontreatmenttoincreasethesolidsolutiondegreeofalloyingelementswhileeffec tivelysuppressingtheincreaseoftherecrystallizationfractionofthealloy thestepwise temperature increasingsolidsolutionisshowninfigure9b whichmeansthatthealloyis firstholdatalowertemperatureforacertaintime andthengraduallyheateduptoahigher temperatureandheldon throughlow temperaturesolidsolution thelow meltingnon equilibriumeutecticphasecanbepreferentiallydissolved andthengraduallyincreasedto exceedthemulti phaseeutectictemperature whichpromotesthemaximumdissolution ofthesolublesecondphaseinthealloy simultaneously therecoverytakesplaceinthe alloyduringthelow temperatureholdingprocess whichsuppressestherecrystallization inthesubsequenthigh temperaturesolidsolution sothatthecomprehensivepropertiesof thealloyaresignificantlyimproved inordertoimprovethestresscorrosionresistance al 7xxx alloy near solvus pre precipitation following high temperature solutiontreatmenthasbeenproposed whichmeansthatsolidsolutionoccursfullyathighmetals 2021 11 x peer review 15 30 solid solution regime al 7xxx alloy developed single stage multi stage solid solution single stage solid solution shown figure 9a refers enhancing solid solution effect alloy element simply increasing final solid solution temperature extending solid solution time condition avoiding burning disadvantage method solid solution degree alloying element recrystallization fraction alloy increase simultane ously increase solution temperature time comprehensive prop erties ageing poor 100 scholar proposed stepwise tempera ture increasing solution treatment increase solid solution degree alloying ele ments effectively suppressing increase recrystallization fraction alloy stepwise temperature increasing solid solution shown figure 9b mean alloy first hold lower temperature certain time gradually heated higher temperature held low temperature solid solution low melting non equilibrium eutectic phase preferentially dis solved gradually increased exceed multi phase eutectic temperature promotes maximum dissolution soluble second phase alloy sim ultaneously recovery take place alloy low temperature holding process suppresses recrystallization subsequent high temperature solid solution comprehensive property alloy significantly improved order improve stress corrosion resistance al 7xxx alloy near solvus metals2021 11 718 15of29 pre precipitation following high temperature solution treatment proposed mean solid solution occurs fully high temperature hold near limit temperature solid solution 101 shown figure 9c cooling temperatureandthenholdsnearthelimittemperatureofsolidsolution 101 asshownin high temperature lower temperature holding super saturation alloy figure9c whencoolingfromahightemperaturetoalowertemperatureandholding reduced temperature decreasing cooling slower rate high super saturationofthealloyisreducedwiththetemperaturedecreasing whencooling temperature lower temperature holding due low speed cooling ataslowerratefromahightemperaturetoalowertemperatureforholding duetothe temperature gradient change little precipitation power small lowspeedofcooling thetemperaturegradientchangesalittle sothattheprecipitation precipitate preferpeonwtiearlliys snmuaclll eaantdest haet ptrheeci pgitraatiens pbroeufenrednatriaiellsy niunc ltehaete ssuatbtsheeqgureanint baoguinndga ries inthe process aging upbrseecqiupeintattaegsi ncganp rogcreosws tuhep aoginn gthper ecbiapsiitsa teosf ctahneg roorwiguinpaol nptrheecibpaistiastoefs heoriginal thereby grainp breocuipnitdaatersy tphreerceibpyi tathteesg rbaeincobmouensd caorayrpsree cainpdita itse sdbiesccoomnteisncuooaursse danisdtriisbdui scontinuous tion residstiastnrcibeu ttioo n tarensds thceorrreosissitoann cies toimstprersosvceodr r oosinon tihsei mopthroevr edh anodn ththeeo tihne rhand intra granularprecipitatesistinyanddispersed andthealloyhashighstrength 102 tra granular precipitate tiny dispersed alloy high strength 102 figurfei9g u rae s9i n gal e ssitnaggeles ostliadgseo sluoltiiodn blu tsiotenp w bi e stteemppweirsaet uterem ipncerreaatsuinreg isnocluretiaosni n gc snoleuatri osnol v ucs pre precipitation followninegara fstoerlvhuigsh ptreem ppreercaitpuriteastoiolunt ifoonll o1w00i n1g0 2a f ter high temperature solution 100 102 duringthesolidsolutionprocess thegrainsize undissolvedsecondphasefraction solid solution process grain size undissolved second phase fraction andsoluteatomdistributionofthealloywillbechanged whichaffectsthemechanical solute atom distribution alloy changed affect mechanical property xuetal 103 performedmulti stagesolidsolutiononaluminumalloyextrusion property xu et al 103 performed multi stage solid solution aluminum alloy ex materialsandcharacterizedandtestedtheirmicrostructureandmechanicalproperties trusion material tahneds pcehcaifiraccsteorliidzesdo luatniodn tpersoteceds sthiseisrh omwincrionstfriugcutruer1e0 aa ndt hme reecshualtnsicaarle shown property spfeicgiufirce 1s0obli dd swoliuthtitohne sporliodcseoslsu tiiso nshteomwpner aintu rfeiagnudreti m10eain ctrehaes erde siutslststr eanrget hincreases shown figure t1o0tbh edm awxiimthu mthaet gso3laidn dstohleuntidoenc

reteamseps eirnatthueres oalindds otliumtioen ipnrcorceeassseodn tihtse condition of450 c 2h 460 c 2h 470 c 2h andtheagingprocesson121 c 5h strength increase maximum g3 decrease solid solution process 133 c 16h aluminumalloyhasexcellentcomprehensivepropertieswithstrengthof condition 450 c 2 h 460 c 2 h 470 c 2 h aging process 828 0mpaandelongationof8 1 121 c 5 h 133 c 16 h aluminum alloy excellent comprehensive property
thestudyofal7xxxalloysfoundthatthesusceptibilitytoexfoliationcorrosionand strength 828 0 pa elongation 8 1 stresscorrosiondecreasesfirstandthenincreaseswiththeincreaseofsolutiontemperature andtime itismainlycausedbythecontinuousdecreaseoftheundissolvedsecondphase andtheconstantlyincreaseofrecrystallizationfraction shatryetal 100 studiedtheeffect ofsolutiontemperatureonthestresscorrosionpropertiesofal7075alloy theyfound thattheelements suchasmg zn cu andsoon migratedtothegrainboundariesduring thesolutionprocess inadditionwiththeincreaseofthesolutiontemperature degreeof atomicaggregationatthegrainboundariesdecreasesfirstandthenincreases resultingin thesusceptibilitytostresscorrosiondecreasesfirstandthenincreases metals2021 11 718 16of29 metal 2021 11 x peer review 16 30 figure10 schematicdiagramofsolutionprocess mechanicalpropertiesofalloys b hardness figure 10 schematic diagram solution process mechanical property alloy b hardness c tensilestrength elongationandthecorrespondingstress straincurvesundert6 t73 t7x c tensile strength elongation reprinted permission ref 103 copyright 2019 elseviaegr n g reprintedwithpermissionfromref 103 copyright2019elsevier 4 2 quenching study al 7xxx alloy found susceptibility exfoliation corrosion
quenchingreferstotheoperationofrapidlycoolingthealuminumalloyaftersolid stress corrosion decrease first increase increase solution tem solutiontonearroomtemperaturethroughacertainmedium suchascoldwater oil etc perature time mainly caused continuous decrease undissolved theintentofquenchingistofixthesupersaturatedsolidsolutioninafastcoolingmanner second phase constantly increase recrystallization fraction shatry et al 100 sothatthealloymaintainsacertainsolutesuper saturationandvacancyconcentration studied effect solution temperature stress corrosion property al 7075 soastofacilitatethediffusionofatomsandtheformationofstrengtheningphasesinthe alloy found element mg zn cu migrated grain subsequentagingprocess 104 boundary solution process addition increase solution quenchingtransfertimeandcoolingratearetwocrucialparametersthataffectthe temperature degree atomic aggregation grain boundary decrease first propertiesoftheagetreatedalloy whenquenching theal7xxxalloysneedtobetrans increase resulting susceptibility stress corrosion decrease first ferredfromthesolidsolutionequipmenttothequenchingequipment 105 asthealloy increase temperaturecontinuestodecrease thesoluteatomsuper saturationcontinuouslyincreases andthesecondphaseiseasytobeprecipitatedfromthesupersaturatedsolidsolution 106 4 2 quenching however theatomicdiffusionratewillconstantlydecreaseasthetemperaturereducing quenching refers operation rapidly cooling aluminum alloy solid resultingindifficultiesintheprecipitationofthesecondphase whenthealloyislowered solution near room temperature certain medium cold water oil etc toacertainintermediatetemperature thesolutesuper saturationandtheatomicdiffusion intent quenching fix supersaturated solid solution fast cooling man ratearerelativelyhigh andthesecondphaseprecipitationratecomesuptothemaximum ner stoh tehaint ttehrem aeldloiyat emtaeimntpaeinrast au rceerrtaanigne siosluretefe srurepdert osaatsutrhaetiqoune anncdh ivnagcsaenncsyi tcivoencreanntgrea ofthe tion saoll aosy tow fahceilnitathtee thque ednifcfhuisniognt roafn astfoemr sti manedi tshleo fnogrmorattihoen qouf estnrcehnigntghecnoionlgin pghraastees iisn slow sutbhseeηqupehnat saegiisnge apsriolycepsrse c1i0p4it ted grain boundary al 7xxx alloy qaguienngc hηinpgh atrsaencsofvere rtaimgeea atnthde cgoroaliinngb oruatned aarreie tswoof tchreuaclilaol ypiasrhamighet ewrsh itchhatr easfufeltcst itnhea high propeirnttieers gorfa nthuel aargceo rtrroesaitoend saelnlosyit vwityhe n10 q7 u einnchadindgi itohne tahel 7laxrxgex aamlloouyns tnoefepdr etoci pbieta tion transfoefrrtehde ηfropmha tsheer esdoluidce ssotlhuetisounp eeqr usiaptmureantito tno othfeth qeuaelnlocyh insog tehqautitphmeeangti n 1g0p5r e caips itthaeti oni alloy dteifmfipcuelrta taunrde cthoentsitnruenesg ttho odfetchreeaaslelo ythies rseodluutcee dat o1m08 utpheer rseaftourrea tiinono rcdoenrttionuoobutasilny high increacsoems p arnedh etnhsei vseecpornodp eprhtiaesseo ifs aeals7yx txox bael lporye ctihpeitqatueedn fcrhoimng tthrea

nssufpeerrtsiamtuermatuedst sboelisdtr ictly solution 106 however atomic diffusion rate constantly decrease tem metal 2021 11 x peer review 17 30 perature reducing resulting difficulty precipitation second phase alloy lowered certain intermediate temperature solute super saturation atomic diffusion rate relatively high second phase precipitation rate come maximum intermediate temperature range referred quenching sensitive range alloy quenching transfer time long quenching cooling rate slow η phase easily precipitated grain boundary al 7xxx alloy aging η phase coverage grain boundary alloy high result high inter granular corrosion sensitivity 107 addition large amount precipitation η phase reduces super saturation alloy metals2021 11 718 17of29 aging precipitation difficult strength alloy reduced 108 therefore order obtain high comprehensive property al 7xxx alloy quenching transfer time must strictly controlled avoid alloy temperature falling controlledtoavoidthealloytemperaturefallingtothequenchingsensitiverange andthe quenching sensitive range alloy temperature must rapidly reduced alloytemperaturemustberapidlyreducedbelowthequenchingsensitiverangewitha quenching sensitive range fast cooling rate 27 107 109 113 fastcoolingrate 27 107 109 113 song et al 110 explored effect different quenching transfer time exfo songetal 110 exploredtheeffectofdifferentquenchingtransfertimeontheexfo liation corrosion al 7050 t6 alloy shown figure 11 resistance exfoliation liationcorrosionofal7050 t6alloy asshowninfigure11 theresistancetoexfoliation corrosion alloy decrease increase quenching transfer time corrosion alloy decrease increase quenching transfer time demonstrated figure coverage rate microstructure grain demonstratedinthefigure thecoveragerateandthemicrostructureofthegrainboundary boundary precipitate important factor affecting property al precipitatesarethemostimportantfactorsaffectingthepropertiesofthealloy andthe loy solute depleted region grain boundary small even effect solutedepletedregionatthegrainboundarieshasasmallevennoeffectontheproperties property figure 11 sem image showing grain sub grain boundary precipitate 7050 t6 alloy figure11 semimagesshowinggrainandsub grainboundaryprecipitatesin7050 t6alloystreated treated different transfer time 2 b 45 c 120 tem image 7050 t6 alloy treated withdifferenttransfertimes 2 b 45s c 120 temimagesof7050 t6alloystreatedwith different transfer time e 2 f g 45 h 120 reprinted permission ref 110 differenttransfertime e 2 f g 45s h 120 reprintedwithpermissionfromref 110 copyright 2014 elsevier copyright2014elsevier thechemicalcompositionisthemostimportantfactoraffectingthequenchingsen sitivityofthealloy thequenchingsensitivitywillbechangedwiththevariationforthe contentorproportionofzn mg andcuelementsinthealloy yuanetal 114 studiedthe corrosionbehaviorofal zn mg cualloysatdifferentcucontentsandquenchingrates showninfigure12 throughtheanalysisofthetensilestrengthandelongationofthealloy itwasfoundthatwiththesamecucontent asthequenchingratedecreases thetensile strengthdecreases andtheelongationincreasesfirstandthendecreases slowquenching ratecaneffectivelyimprovethesccresistanceofcu lowalloys especiallyreducingthe crackgrowthrate whichmeansthatsccpropagationvelocityofcu lowalloyswiththe slow quenching rate order magnitude lower fast quenchingrate however theslowquenchingratehaslesseffectonthecu richalloys metal 2021 11 x peer review 18 30 chemical composition important factor affecting quenching sen sitivity alloy quenching sensitivity changed variation content proportion zn mg cu element alloy yuan et al 114 studied corrosion behavior al zn mg cu alloy different cu content quenching rate shown figure 12 analysis tensile strength elongation alloy found cu content quenching rate decrease tensile strength decrease elongation increase first decrease slow quenching rate effectively improve scc resistance cu low alloy espe cially reducing crack growth rate mean scc propagation velocity cu low alloy slow quenching rate order magnitude lower metals2021 11 718 18of29 fast quenching rate however slow quenching rate le effect cu rich alloy figure 12 schematic diagram heat treatment processing alloy b c tensile strength figure12 schematicdiagramofheattreatmentprocessingforalloys b c tensilestrengthandelongationcurveofthe elongation curve well quenched aged sample treated different quench rate effect well quenchedandagedsamplestreatedbydifferentquenchrate effectofcucontentandquenchrateonareafraction cu content quench rate area fraction gbps alloy e f effect cu content ofgbpsinalloys e f effectofcucontentandquenchrateonthesizeofgbpsandwidthofpfzsinalloys reprinted quench rate size gbps width pfzs alloy reprinted ref 114 fromref 114 quenching due different cooling rate surface core duringquenching duetothedifferentcoolingratesofthesurfaceandthecorein al 7xxx alloy microstructure residual stress alloy unevenly dis al 7xxx alloy microstructure residual stress alloy unevenly tributed resulting reduction stress corrosion resistance therefore new distributed resulting reduction stress corrosion resistance therefore new quenching process required improve alloy property xie et al 115 studied quenchingprocessisrequiredtoimprovethealloyproperties xieetal 115 studiedthe effect step quenching aging heat treatment stress corrosion cracking prop effectofstepquenchingandagingheattreatmentonthestresscorrosioncrackingproperties erties alloy result show step quenching significantly improve ofthealloys theresultsshowthatstepquenchingcansignificantlyimprovethestress stress corrosion resistance shown figure 13 stress corrosion cracking corrosionresistance asshowninfigure13 thestresscorrosioncrackingresistancehas sistance significantly improved step quenching aging heat treat beensignificantlyimprovedthroughstepquenchingandagingheattreatment butithas ment habse ebnehena rdhlayrdimlyp irmovperdovthedro uthgrhotuhgehr etghree srseigornesasgioinng aagnidngtw aon dst atgweoo svtearg ea gingtreatment aging treactommepnat rceodmwpiathrepde awkitahg ipnega kf oargcinug l ofwora cl uz nlo mwg cl uzanl lmoygs cthue astllroeysss c othrreo sionresistance stress corrosionw raessiismtapnrcoev wedasa fitmerpsrtoevpeqdu aefntecrh sintegpa qnudeangcihnigngh eaantdt raegaitnmge hnet amt tarienaltymbeencta useofthehigh metal 2021 11 x peer review 19 30 mainly becausec uofc othnete nhtig lha rcgeu scizoen taenndt dlaisrcgoen tsiinzue uansdd isdtirsicbountitoinnuoofugsr adiinstbriobuuntdioanr yopf recipitates grain boundary precipitate figure 13 schematic diagram heat treatment alloy investigated b dependence figure13 schematicdiagramofheattreatmentforthealloysinvestigated b dependenceof stress corrosion cracking propagation rate v stress intensity factor ki different heat stresscorrosioncrackingpropagationrate v andstressintensityfactor k ofdifferentheattreat treatment specimen c v■ kiscc value different heat treatment reprinted pier mission fromm erenft 1s1p5e c cimopeynrsi g hct 2v01ii9a enldsevkieisrc c valuesofdifferentheattreatments reprintedwithpermission fromref 115 copyright2019elsevier chen et al 27 explored effect quenching rate microstructure stress corrosion property al 7085 alloy decrease quenching rate size inter particle distance grain boundary precipitate precipitation free zone width increase cu content precipitate decrease addition stress corrosion resistance alloy increase first decrease de crease quenching rate shown figure 14 according analysis size dis tribution cu content precipitation grain boundary main factor affecting stress corrosion resistance alloy metal 2021 11 x peer review 19 30 figure 13 schematic diagram heat treatment alloy investigated b dependence metals2021 11 718 stress corrosion cracking propagation rate v stress intensity factor ki different heat 19of29 treatment specimen c v ■ kiscc value different heat treatment reprinted per mission ref 115 copyright 2019 elsevier chen et calh e n27e aelx p 2lo7r eedx ptlhoer eedfftehcet eofff eqctuoefnqchuienngc hriantge roante tohne tmheicmroicsrtrousctrtuucrteu raendan dstress stress corcroorsrioosnio pnropproerpteiersti eosf aofl a70l8750 8a5lloayll wy itwh itthhe tdheecdreeacsree aosfe thofe tqhueeqnuchenincgh irnagter athtee size andinter particledistanceofthegrainboundaryprecipitatesandprecipitationfreezone size inter particle distance grain boundary precipitate precipitation free width increase cu content precipitate decrease addition stress zone width increase cu content precipitate decrease addition corrosionresistanceofthealloyincreasesfirstandthendecreaseswiththedecreaseofthe stress corrosion resistance alloy increase first decrease de quenchingrate asshowninfigure14 accordingtoanalysis thesize distribution crease quenching rate shown figure 14 according analysis size dis thecucontentoftheprecipitationsatthegrainboundariesarethemainfactorsaffecting tribution cu content precipitation grain boundary main thestresscorrosionresistanceofthealloy factor affecting stress corrosion resistance alloy figure14 ssrtresultsforaa7085withdifferentquenchingrates inair b in3 nacl 0 5 h solution temmicrostructuresofalloyswithdifferentquenchingconditions c 150 c 2 2 50 c e 1 c reprintedwithpermissionfromref 27 copyright2012elsevier 4 3 aging agingisamainmethodtooptimizethemicrostructureandcomprehensivepropertiesof al7xxxalloys aftersolidsolutionandquenchingofal7xxxalloys thealloyelementsare inasupersaturatedstate andthedislocationdensityishigh whilekeptatroomtemperature thatisnaturalaging itiseasyforthesecondphase whichmeansmainlygpzonesinal 7xxxalloys toprecipitatefromthealloy sothatthealloyisstrengthened 80 116 however thisprocessisextremelylong evenafterkeptforayear thealloycannotreachastablestate anditsstrengthisstillslowlyrising 117 asshowninfigure15 intheactualproductionprocess artificialagingisusuallyusedtoachievethedesired property alloy aging precipitation process quenched alloy acceleratedbyholdingatahighertemperature 118 theartificialagingstateofal7xxx alloyshasinturnexperiencedthedevelopmentprocessofpeakaging t6 aging t7x retrogression aging rra general precipitation order secondphaseintheal7xxxalloysduringtheartificialagingprocessissupersaturated solid solution ss vacancy rich cluster gpiizones η spherical η platelet 119 121 inal7xxxalloysforaircraft despitethesecondphaseswithgpzones η η mgzn otherprecipitatescanbealsoformed 42 119 122 asshownintable4 2metals 2021 11 x peer review 20 30 figure 14 ssrt result aa7085 different quenching rate air b 3 nacl 0 5 h2o2 solution tem microstructures alloy different quenching condition c 150 c 50 c e 1 c reprinted permission ref 27 copyright 2012 elsevier 4 3 aging aging main method optimize microstructure comprehensive proper tie al 7xxx alloy solid solution quenching al 7xxx alloy alloy element supersaturated state dislocation density high kept room temperature natural aging easy second phase mean mainly gp zone al 7xxx alloy precipitate alloy alloy metals2021 11 71s8trengthened 80 116 however process extremely long even kept 20of29 year alloy reach stable state strength still slowly rising 117 shown figure 15 figure15 mechanicalpropertiesoftheal7xxxalloysduringnaturalaging 116 figure 15 mechanical property al 7xxx alloy natural aging 116 actuatl apbrloed4u cotibosne rpvreodcpesrse c iaprittiafitceisailn aagiirncrga fit aulsualalollyy pursoeddu ctots 4c2h i1e1v9e 1 t2h2e de sired property alloy aging precipitation process quenched alloy accelerated holding higher atellmoyperature 118 artificial aging ostbastee rovfe dapl recipitate 7xxx alloy turn experienced7x 7th5e development process peak aginga lt6m g cr 12 2 aging t7x retrogression a7nxd50 aging rra general precipitataiolnz r 3 order second phase al 7x7x0x55 alloy artificial aging process asul 3 zr persaturated solid solution ss to7 xva7c5a tn6cy rich cluster gph■ zaopnreesc u tros oηr shp hmergi zn 2ormg zn cu al 2 cal η platelet 119 121 al 7xxx alloy aircraft despite second phase gp4 z3o 1n eps e ak ηa g g η mgzn2 precipitate also formed 42 119 122 shown table 4 peak aging aging heat treatment method maximizes strength metal 2021 11 x peer review 21 30 alloy order make alloy obtain peak strength necessary precipitate table 4 observed precipitate aircraft al alloy product 42 119 122 tinyanddispersedparticleswithinthegrainstoobstructthedislocationmotionduring daeflloorym ation onlythecoherentgpozbosneervseadn pdretchipeitsaetem coherentη mgzn phasewith 2 deformati h7n ex 7 mo5 n al ty ri xth ie n c aoh le 7r xe xnt x g ap oz yon se c nan ed f ft eh ce ti vsae elm l12ymi pcgo i2nchre bt ilη e dm isg lz c2a ip oh na sse nw dit ah r efunctioned matrix s7inx t5a r0 e l n 7 gx tx hex n inll goy 1 2c 3a n tef hfe ec rt eiv foe rly e p thin e ago ib ni galel 3d ez mirs l po eca rati un r e sn hd ua lr de bfu en cc oti tn od edbelowthe strengthe7n05in5 g 123 therefore aging temperatuarel3 zsrh ould controlled melting point gp zone heating rate controlled large melting p7oxin75t ot6f gp zone thhe ha eparteicnugr sroar tteo shh mouglzdn b2 oer cmong tzronl cleud sl o2 large number gp zone first precipitated within grain appropriately number gp zone first precipitated within grain appropriately transformedto η phase finally thetinyand dispersedparticles mainlyincluding 4 3 1 peak aging transformed η phase finally tiny dispersed particle mainly including gpzonesandη phaseareformedinthegrains whichmakesthealloyobtainthehighest pegakp azgoinnegs iasn adn ηa gpinhgas eaarte tfroeramtmeedn itn theteh gorda itnhsa wmhaicxhim mizaekse tsh teh est raellnogyt ho botfa itnh et high strength 41 however becausetheagingtemperatureisoftenlowortheagingtimeis alloy iens srdtreern tgot hm a4k1 e thhoe walelvoyer bbetacianu tshee hpee aakg isntgre tnegmthp e irta itsu rnee cise sosfatreyn tloo wp roerc itphieta ateg ing time relatively short alloy element especially cu element occur incomplete diffusion tiny anids rdeilsapteivrseelyd sphaorrtitc ltehse w ailtlhoiyn etlheem gernatisn se stop eocbiastlrlyu cct uth eel edmiseloncta toicocnu mr iontcioonm dpulertien gd iffusion resultinginahighpotentialdifferencebetweenthegrainsandgrainboundariesinthisheat resulting high potential difference grain grain boundary treatmentmethod meanwhile asshowninfigure16 duetothecontinuityofchain like heat treatment method meanwhile shown figure 16 due continuity grainboundaryphasesofthet6statealloy itiseasytobecomeacontinuouschannelfor chain like grain boundary phase t6 state alloy easy become continuous corrosionexpansion sothatthelocalizedcorrosionsusceptibilityishigh channel corrosion expansion localized corrosion susceptibility high figure 16 distribution grain boundary precipitate t6 high strength aluminum alloy tem figure16 distributionofgrainboundaryprecipitatesoft6highstrengthaluminumalloy tem b sadps reprinted permission ref 120 copyright 2015 elsevier b sadps reprintedwithpermissionfromref 120 copyright2015elsevier 4 3 2 aging aging heat treatment method developed improve corrosion sistance t6 state alloy aging heat treatment corrosion resistance alloy improved residual stress correspondingly reduced also di mensional stability alloy high temperature environment enhanced make service environment service life alloy expanded improved however come expense losing partial strength strength al zn mg cu alloy t73 t74 state 10 15 lower t6 state alloy according literature 124 125 order shorten time alloy reach ageing state aging treatment usually adopts two stage aging including aging heat treatment method low temperature first high temperature high temperature first low temperature t74 t736 typical ageing heat treatment low temperature treatment followed high temperature treatment first stage low temperature aging pre aging purpose precipitating fine dispersed gp zone alloy grain second stage high temperature aging stabilization stage aging process gp zone gradually transforms η η phase grows grain boundary precipitate coarse discontinuously distrib uted also intra granular precipitate grow distributed unevenly ultimate ly corrosion resistance alloy increase strength decrease shown figure 17a 126 128 high temperature followed low temperature aging heat treatment method dissolve small amount gp zone high temperature aging increase degree super saturation alloy precipitate large number fine dispersed strengthening phase within grain low temperature aging partial η phase precipitated high temperature aging stage due high melting point η phase dif ficult dissolve high temperature stage become nucleation point low temperature aging stage promotes nucleation growth grainmetals2021 11 718 21of29 4 3 2 aging anover agingheattreatmentmethodisdevelopedtoimprovethecorrosionresistance ofthet6statealloy afterover agingheattreatment thecorrosionresistanceofthealloy isimproved andtheresidualstressiscorrespondinglyreduced also thedimensional stability alloy high temperature environment enhanced make serviceenvironmentandservicelifeofthealloyexpandedandimproved however comesattheexpenseoflosingpartialstrength thestrengthoftheal zn mg cualloy inthet73andt74statesis10 15 lowerthanthatofthet6statealloyaccordingtothe literature 124 125 inordertoshortenthetimeforthealloytoreachtheover ageingstate theover aging treatment usually adopts two stage aging including aging heat treatment method oflowtemperaturefirst thenhightemperatureorhightemperaturefirstandthenlow temperature t74 t736 isatypicalover ageingheattreatmentthroughlowtemperature treatmentfollowedbyhightemperaturetreatment itsfirst stagelow temperatureaging ispre agingwiththepurposeofprecipitatingfineanddispersedgpzonesinthealloy grain thesecond stagehigh temperatureagingisastabilizationstage duringtheaging process thegpzonesgraduallytransformstoη andηphaseandgrows andthegrain boundaryprecipitatesarecoarseanddiscontinuouslydistributed also theintra granular precipitatesgrowandaredistributedunevenly ultimately thecorrosionresistanceofthe alloyincreases andthestrengthdecreases asshowninfigure17a 126 128 thehigh temperaturefollowedbylow temperatureagingheattreatmentmethodistore dissolve asmallamountofgpzonesthroughhigh temperatureaging whichincreasethedegree ofsuper saturationofthealloy andthenprecipitatealargenumberoffineanddispersed strengtheningphaseswithingrainsthroughlow temperatureaging thepartialηphase metal 2021 11 x peer review 22 30 canbeprecipitatedduringthehigh temperatureagingstage duetothehighmeltingpoint η phase difficult dissolve high temperature stage become nucleationpointatthelow temperatureagingstage whichpromotesthenucleationand boundary precipitgartoews tahso fa trheesuglrta itnheb opurencdiparityatperse cairpei tcaotaerss ea asnda rdeissucoltn ttihneuopuresclyip ditiast e coarse tributed shownd iisnc ofnigtuinrue o1u7sbl 1d2i8s r ibuted asshowninfigure17b 128 figure 17 precipitate distribution near grain boundary two stage aging t74 b figure17 precipitatedistributionnearthegrainboundaryoftwo stageoveraging t74 b high high temperature followed low temperature aging 126 128 temperaturefollowedbylow temperatureaging 126 128 4 3 3 retrogressio4n 3 3n dr reetr oaggriensgsi onandre aging order make ianl o7rxdxerxt oalmloyask ehaavle7 hxixgxh acollroryossihoanv reehsiisgthanccoer rwoshiiolen mreasiinsttaaninciengw hilemaintaining high strength cinhai geht aslt r e 1n2g9t h p croipnoaseetda tl h e1 2h9e apt rtroepaotmseedntth perhoceeastst roefa rtmetreongtrpersosicoens saonfdr etrogressionand aging rra r1e9 a7g4i nrge rtrroagr eisnsi1o9n7 4a nrde trreo gagreinssgio in aanctdurael lyag tghriseea csttuaaglely aagitnhgre etr estaatg eagingtreatment ment method whmichet hinocdlu wdehsi cphrein acgluindge rpertero aggriensgs iorent r aongdre rsesi oang inagn prree aaggiinngg mpreea angsi ntog meanstokeepat keep low temapleorwatuterme pfoerr aat ulornegfo preariloodn gofp etirmioed orfettirmoger ersseitornog irse asslwioanyiss tahlwroauygsht har oughacompara comparatively higtihv etleymhpigehratteumrep efroart uar esfhoorrat stihmoret trime ea grine ga grienfgerrse fteor skteoekpe eapt aat alolwowere rtemperaturefor temperature alolnong gppereiroidod 1 3103 0 rra treatmaefntte r trhrea sttrreenatgmthe notf tthhees tarlelnogyt hiso cfltohseea tlloo ythise cploesaekt atnhed ptehaek satrnedsst hestresscorrosion corrosion resistanrcees stfaranccteu rfera ctotuurgehtnoeusgsh naensds afantdigfuaeti grueesirsetasinsctaen caerea rseigsniginfiicfaicnatnlytl yimim proved 131 134 proved 131 134 titi sisa tattrtirbiubutetdedt ototh teher ergeuglualtaiotinono forf rrarao nonth tehme imcriocsrotrsutrcutucrteuroef othf ethaell oy including alloy including composition morphology distribution precipitate however different view put forward microstructure evo lutions different stage based research result general rra treat ment gp zone precipitated pre aging stage properly transforms η phase grows stage high temperature retrogression finer gp zone η phase dissolved grain boundary precipitate almost dissolution due large size transformed stable η phase 37 131 aging process fine dispersed gp zone η phase precipitated alloy grain grain boundary precipitate nucleate grow based existing precipitate eventually become discontinuously dis tributed 36 135 137 shown figure 18 figure 18 microstructure change near grain boundary rra treatment reprinted permission ref 36 copyright 2020 elsevier metal 2021 11 x peer review 22 30 boundary precipitate result precipitate coarse discontinuously dis tributed shown figure 17b 128 figure 17 precipitate distribution near grain boundary two stage aging t74 b high temperature followed low temperature aging 126 128 4 3 3 retrogression aging order make al 7xxx alloy high corrosion resistance maintaining high strength cina et al 129 proposed heat treatment process retrogression aging rra 1974 retrogression aging actually three stage aging treat ment method includes pre aging retrogression aging pre aging mean keep low temperature long period time retrogression always comparatively high temperature short time aging refers keep lower temperature long period 130 metals2021 11 718 rra treatment strength alloy close peak stress 22of29 corrosion resistance fracture toughness fatigue resistance significantly im proved 131 134 attributed regulation rra microstructure alloy including composition morphology distribution precipitate composition morphology anddistributionoftheprecipitates however therearedifferent however different view put forward microstructure evo viewswhichwereputforwardonthemicrostructureevolutionsatdifferentstagesbased lutions different stage based research result general rra treat research result general rra treatment gp zone precipitated ment gp zone precipitated pre aging stage properly transforms duringthepre agingstageandproperlytransformstotheη phaseandgrows inthestage η phase grows stage high temperature retrogression finer gp ofhigh temperatureretrogression thefinergpzonesandη phasearere dissolved zone η phase dissolved grain boundary precipitate almost grain boundary precipitate almost dissolution due large size dissolution due large size transformed stable η phase transformed stable η phase 37 131 aging process 37 131 aging process fine dispersed gp zone η phase fineanddispersedgpzonesandη phasearere precipitatedinthealloygrains andthe precipitated alloy grain grain boundary precipitate nucleate grainboundaryprecipitatescannucleateandgrowbasedontheexistingprecipitates grow based existing precipitate eventually become discontinuously dis eventuallybecomediscontinuouslydistributed 36 135 137 asshowninfigure18 tributed 36 135 137 shown figure 18 metal 2021 11 x peer review 23 30 figure18 mfiigcruorset r1u8c umreiccrhoasntrguecstunreea rchgaranignebso nuenadr agrrieasind ubroiunngdrarriaest rdeuartminegn rt r aa ptrreea atmgienngt b r reeptrroingtreeds swiointh c aging reprintedwpeitrhmpisesrimonis fsrioomn frreofm 3re6f c3o6p ycriogphyt r2ig02h0t 2e0ls2e0veielsre v ier yang et al 12y0a n gstuetdaiel 1t2h0e mstuecdhieadnicthael amnedc hcaonrircoaslioann drecsoirsrtaonsicoen prreospisetartniecse pofr operties al al 6 0zn 2 3mg6 01z 8nc u2 30m 1gz r1 8wctu 0 1 zarll owy n adlilfofyeroenntd iaffgeirnegn ttaregaintmgterneta tcmoenndtitcioonnds tiaons asshownin shown figufreig 1u9re t1h9e trherrar satasttea theahsa hsihgihgehre rstsrterennggthth aanndd bbeettteerr ccoorrrroossioionnr erseissitsatnacneceth antheroutine t6andt74states theoptimalprocessfortheexperimentalalloyisontheconditionsof routine t6 t74 state optimal process experimental alloy 120 c 24h 180 c 60min 120 c 24h condition 120 c 24 h 180 c 60 min 120 c 24 h figure19 fai gmureec 1h9a n iac lmperochpaenrtiiceasl pinrotepregrrtaiensu lianrtecrogrrraonsuiolnarm coorrrpohsoiolong myoorfpthhoeloagllyo yofu nthdee raldloifyf eurenndtera gdinifg treatment ferent aging treatment condition b t6 c t74 rra40 e rra60 reprinted permis condition b t6 c t74 rra40 e rra60 reprintedwithpermissionfromref 120 copyright2015elsevier sion ref 120 copyright 2015 elsevier chenetal 41 exploredtheeffectsofagingtreatmentonstresscorrosioncracking chen et alf r a4c1t u erexptolourgehdn tehses eafnfedctsst roefn aggthinogf tarela7tm08e5nat lolony staressssh coowrrnosiniofni gcruarcek2in0 gc omparedwith fracture toughness strength al 7085 alloy shown figure 20 compared t6 state fracture toughness t74 state improved 22 9 strength reduced 13 6 fracture toughness rra state 14 2 higher t6 state strength almost unchanged fracture toughness drra t74 state comparable former strength increased 14 6 com pared latter figure 20 ssrt result aa7085 different aging regime air b 3 nacl solution reprinted permission ref 41 copyright 2014 elsevier lin et al 138 researched effect different aging treatment tensile strength stress corrosion resistance al 7050 alloy 3 5 nacl solution ph12 shown figure 21 tensile strength improved t6 state stress corro sion resistance reduced contrast stress corrosion resistance t74 state im proved tensile strength reduced tensile strength stress corrosion metal 2021 11 x peer review 23 30 yang et al 120 studied mechanical corrosion resistance property al 6 0zn 2 3mg 1 8cu 0 1zr wt alloy different aging treatment condition shown figure 19 rra state higher strength better corrosion resistance routine t6 t74 state optimal process experimental alloy condition 120 c 24 h 180 c 60 min 120 c 24 h figure 19 mechanical property intergranular corrosion morphology alloy dif ferent aging treatment condition b t6 c t74 rra40 e rra60 reprinted permis sion ref 120 copyright 2015 elsevier metals2021 11 718 23of29 chen et al 41 explored effect aging treatment stress corrosion cracking fracture toughness strength al 7085 alloy shown figure 20 compared t6 state fratc6tusrtea tteo utghhenfreascst oufr ethteo utg7h4n setassteo ifst ihmeptr7o4vsetda tbeyi s22im 9p r bvuetd tbhye s2t2r e9n g thb uist thestrengthis reduced 13 r6e u tcehde bfrya1ct3u 6r e totuhgehfnraecstsu oref ttohue grhrnaes sstoafteth y r14r a2 st ahtieghise1r 4t h2a n htihgahte orft hanthatofthe t6 state antd6 tshtea tset reanngdthth y satlrmenogstth uinscahlamnogsetdu ntchhea nfrgaecdtu rteh teoufrgahcntuerses toofu tghhen desrsroaf thedrraand t74 state 7c4omstaptaeriasbcleo bpuatr tahbele f obrumtetrh estfroernmgethr sitsr einncgrtehaissedin cbrye a1s4e d6 b yw1h4i c6h cwomhi chcomparedto pared lattthere latter figure 20 ssrt result aa7085 different aging regime air b 3 nacl solution figure 20 ssrtresultsofaa7085underdifferentagingregimes inair b in3 naclsolution reprintedwith reprinted permission ref 41 copyright 2014 elsevier permissionfromref 41 copyright2014elsevier metal 2021 11 x peer review 24 30 lin et al 138 researched effect different aging treatment tensile lin et al 138 researched effect different aging treatment tensile strength stress corrosion resistance al 7050 alloy 3 5 nacl solution ph12 strengthandstresscorrosionresistanceofal7050alloyina3 5 naclsolutionatph12 sa i nh co ew r ei n b f oi tag hsu ersneh ho2 aw1 n n cth einde ft ie nign u thirleee 2rs1t rr etahn eg sttthea nti es lwiem hsp itcrrehon v ige std hm iin u citmh6 p bsretoa tvtt eeer b tihunat tnth6 tesh tesat tr oee hb eu c rt ttr whreo tresscorrosion msio etn h ore d si ance riess irsetdauncceedis irne dcuocnetdra sitn tchoen tsrtarests st hcoersrtorseisosnc orerrsoisstiaonncere osifs tta7n4c estoaftet i7s4 ismta teisimproved proved theb utetntshielet esntrseilnegstthr eins grtehdiuscreedd utcheed tetnhseiltee nstsrielengsttrhe nagntdh satnredssst rceosrsrocsoirorno srieo nresistanceare bothenhancedintherrastatewhichismuchbetterthantheothertwomethods figure21 fsisgrutrer e2s1u lstssorft7 r0e5s0uwltsi tohf d7i0f5fe0r ewnittha gdiinffgerreengtim ageisn ga reingiamire sb ai n in3 airn abc lin o3l ut inona c lc sovlaurtiiaotnio n c fcorrosion potentialwviathriatitmioen foofr cvoarrrioosuiosns ppeoctiemnteinasl winit3h 5t imne afocrl vsoarluiotuiosn saptecpihm1e2n irn e3p 5ri nt endawcli tsholpuetriomni sasti opnhf1ro2 ref 138 copyright 2r0e0p6reinlsteevdi ewr h permission ref 138 copyright 2006 elsevier wang et al 36w aenxpgloerteadl h3e6 efefxepctl oorfe drrthae oefnf etchteo mf ricrroastoruncttuhree hicarrodsnterussc taunrde hardness corrosion resistcaonrcreo soifo nalr e7s0is8t5a naclleoyo f iat lsh70o8w5s atlhloayt thite sphroowpsertthieast othf eapl r7o0p8e5r taiellsoyo faarel 7085 alloy sensitive temspeenrsiintgiv teetmopteemraptuerrein agntde mtimpeer aatusr sehaonwdnt iimn ef igausresh 2o2w tnhein aflliogyu crean2 2o btthaeina lloycanobtain good mechanicgaol oadndm ceocrhraonsiicoanl raensdistcaonrcreo spiornopreerstiisetsa nocne cpornodpietirotine soof n12c0o n dci io 2n4o hf 1 2 0 c 24 h 160 c 1 5 h 1 16200 cc 214 5hh c om12p0a rced w2it4h hth ec poemakp aargeidngw tihthe thhaerdpneeasks aogf irnrg hise ihna rdness rra creased 10 2 iwnchriecahs emdabinyly1 0a t2tr ib uwteh tioch thme adiinslpyerastetrdib ruotde ltioket hηe pdhiasspee rinse tdher omda ltirkixe η phase also corrosmioantr rixe siastlasno ceth y ciomrprorsoivoendr edsuiset atnoc tehies cimoaprrsoev ηe pdhuaeseto otfh tehceo dairsscereηt ep dhiass eofthediscrete tribution formeddi sbtryi btuheti ohnigfhoermr cedu bcyonthteenht iganhder tchue ncoanrrtoenwt apnrdectihpeitantaer rforewe pzroenceip witahtiec hf reezonewhich approximataelrye 4a5p p5r0o xnimm aatleolnyg4 t5h e5 0grnamina bloonugndthaeriegsr inboundaries figure 22 hardness conductivity 7085 alloy different aging condition b effect retrogression treatment value ecorr maximum corrosion depth igc test printed permission ref 36 copyright 2020 elsevier 5 conclusion main part high strength aluminum alloy al 7xxx alloy suc cessfully used main material aircraft structural component applica tion titanium alloy composite material fuselage design proportion aluminum alloy reduced order aluminum alloy remain attractive airframe construction research necessarily carried term struc tural property weight reduction cost reduction therefore current study al 7xxx alloy contain improvement mechanical property reduction manufactur metal 2021 11 x peer review 24 30 sistance enhanced rra state much better two method figure 21 ssrt result 7050 different aging regime air b 3 nacl solution c variation corrosion potential time various specimen 3 5 nacl solution ph12 reprinted permission ref 138 copyright 2006 elsevier wang et al 36 explored effect rra microstructure hardness corrosion resistance al 7085 alloy show property al 7085 alloy sensitive tempering temperature time shown figure 22 alloy obtain good mechanical corrosion resistance property condition 120 c 24 h 160 c 1 5 h 120 c 24 h compared peak aging hardness rra creased 10 2 mainly attribute dispersed rod like η phase matrix metals2021 11 718 also corrosion resistance improved due coarse η phase discrete dis 24of29 tribution formed higher cu content narrow precipitate free zone approximately 45 50 nm along grain boundary figure 22 hardness conductivity 7085 alloy different aging condition b effect figure22 hardnessandconductivityof7085alloywithdifferentagingconditions b effectof retrogression treatment value ecorr maximum corrosion depth igc test retrogressiontreatmentonthevaluesofecorrandmaximumcorrosiondepthinigctest reprinted printed permission ref 36 copyright 2020 elsevier withpermissionfromref 36 copyright2020elsevier 5 co5n ccluosnicolnuss ion thaes mthaeinm paainrtp oafr thoigfhh isgtrhesntgrethn gatlhumaliunmumin uamlloayl l oayl a7xlx7xxx axlloayllso yhsavhea vbeeebne esnucsu ccess cessffuullllyy uusseedd aas tthhee mmaaiinn mmaatteerriiaallss ooff aaiirrccrraafftt ssttrruuccttuurraall ccoommppoonneennttss wwiitthh tthhee aapppplliiccaa tionof tion toitfa tnitiaunmiuamll oayllsoaynsd acnodm cpoomspitoesmitea tmeraiatelsriianlst hine ftuhsee flaugseeldagesei gdne stighne p trhoep porrotipoonrotifoanl uomf inum alumailnlouymh aalslobye ehnasr ebdeuecne dre diuncoerdd eirn foorrdaelru mfoirn aulmumailnlouyms taollroeyms atoin raetmtraaicnt iavtetriancttihveea iinr frame aciorfnrsatmruec tcioonns trreuscetaiornch rsehsoeuarldchb sehnoeucleds sbaer inlyecceasrsraieridlyo cuatrirnietde romust oinf stterrumcstu orfa lsptrruocp erties turalw periogphetrrteidesu cwtioeing hatn rdedcouscttiroend u acntido nc otsth reeredfuocrtei ocnu rtrehnetresftourdei e scuforrreantl 7stxuxdxieas llfooyr saclo ntain 7xxxim apllrooyvse cmoenntatsino inmmpreocvheamniecnatlsp oronp meretciehsa nriecdalu pctrioopneortfiems rneudfuaccttiuornin ogf mmaaninutfeanctaunrc e repaircosts preventionofcorrosionandfatigue andabilitytoperformreliablythroughout itsservicelife inrecentyears al7xxxalloyshavesuccessfullyimprovedstaticstrength fracture toughness fatigueandcorrosionresistancethroughcompositiondesignandcontrolof chemical composition well via exploitation efficient heat treatment method itcanbeseenfromthisreviewthatthemainimprovementofal7xxxalloysisto 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comprehensive property al 7xxxalloys
itisnecessarytoimprovetheexistingheattreatmentregimeordevelopa newone inbrief
thedevelopmentofnewgenerational7xxxalloysforaircraftstructure shouldgiveconsiderationtohighstrength
hightoughness highdamagetolerance high quenching andgoodcorrosionresistance
thedevelopmentsofmanufacturingtechniquesarethekeyissuesfortheweightand
costreductionexceptfortheimprovementonthestructuralperformance manufacturing
occupiesthebiggestportionofthefuselagecost therefore novelassemblytechniques
includinglaserbeamweldingandfriction stirwelding high speedmachiningandam
techniqueshouldbeintroducedtoreducetheproductioncostsandpartcount inaddition
al7xxxalloysissusceptibletocorrosionbyenvironmentduringaircraft service impact life reliability aircraft
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