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available online www sciencedirect com journal magnesium alloy 11 2023 3609 3619 www elsevier com locate jma review application magnesium alloy aerospace review jingying baia b yan yanga chen wenb jing chena gang zhoua bin jianga xiaodong penga fusheng pana school material science engineering chongqing university chongqing 400044 china b beijing spacecraft manufacturing co ltd china academy space technology beijing 100094 china received 29 june 2023 received revised form 13 september 2023 accepted 18 september 2023 available online 4 november 2023 abstract increasingly excellent performance magnesium alloy material magnesium alloy increasingly widely used urgent need weight reduction aerospace application however due severe aviation environment strength corrosion resistance electrical conductivity magnesium alloy material need improved many scholar committed studying higher comprehensive mechanical property besides studied surface treatment process space application characteristic high emissivity oxidation high anti corrosion electroplating improve safety reliability magnesium alloy expand application paper discus several kind magnesium alloy summarizes research progress whole manuscript revised expert experience english writing time surface treatment magnesium alloy material aerospace analyzed besides application magnesium alloy aerospace field summarized depth research many scholar improvement material property development surface protection functional technology believed magnesium alloy used aerospace application make contribution aerospace field 2023 chongqing university publishing service provided elsevier b v behalf keai communication co ltd open access article cc license http creativecommons org license 4 0 peer review responsibility chongqing university keywords magnesium alloy aerospace application review surface treatment 1 introduction must consider strength modulus adaptability space environment electrical conductivity anti corrosion development space technology urgent property 9 13 reduce weight structural material improve car development magnesium alloy application rying capacity payload comprehensive performance magnesium alloy space aerospace field become spacecraft magnesium mg alloy great advantage diverse used structural material low density high specific strength good biocompat energy material including rocket planetary mission ibility good electromagnetic shielding ideal resource utilization spacecraft 14 17 metal structure material weight reduction aerospace ap magnesium combustion co 2 considered pri plication 1 3 however spacecraft go mary energy production cycle 16 order fully develop special service environment launch vibration vac resource mar mission mg powder employed uum atomic oxygen ultraviolet irradiation electron irradia react co 2 found mg powder liquid tion environment 4 6 manned space mission environ co 2 bipropellant rocket engine work properly delivering ment 7 8 structural material used aerospace qualified ignition good combustion performance shown fig 1 18 19 200 kg hopper 25 corresponding author 30 kg co 2 mg rocket propulsion system 9 13 kg co 2 acquisition unit perform 10 15 hop mar surface e mail address yanyang cqu edu cn yang 13552907280 163 com c wen total range 10 15 km 180 martian day http doi org 10 1016 j jma 2023 09 015 2213 9567 2023 chongqing university publishing service provided elsevier b v behalf keai communication co ltd open access article cc license http creativecommons org license 4 0 peer review responsibility chongqing university3610 j bai yang c wen et al journal magnesium alloy 11 2023 3609 3619 fig 1 experimental system powdered mg liquid co2 result stable flame different operating condition b 18 significantly increase range hopper decrease 2 1 free mg alloy duration mission 20 magnesium found form olivine mg according whether main element added rare fe 2 sio 4 containing 32 magnesium oxide mgo 21 earth element magnesium alloy divided magnesium used form stand alone structural mem free mg alloy containing mg alloy free mg bers unique physical characteristic elec alloy mainly include mg al based mg zn based alloy tromagnetic shielding make suitable extrater mg al based alloy widely used including az restrial construction 22 23 reduce cost sustained series mg al zn series mg al mn series space program magnesium obtained asteroidal mg al si etc 33 mg zn alloy poor high tempera planetary soil identified possible fuel hy ture performance aging strengthening ability weak brid rocket propellant thereby facilitating exploration 49 appropriate addition zirconium zr refine industrialization inner solar system 24 grain improve mechanical property alloy zk proposed use combustion lunar regolith mg series mg zn zr one widely used mg zn production construction material moon based alloy 50 mission 25 az series widely used die casting mag paper

focused application magne nesium alloy however mechanical property az sium alloy spacecraft application need spe series relatively poor far much research cial property magnesium alloy space service carried solve problem including adding alloying viewed discussing difference surface function element 29 41 work hardening 36 49 etc idris gokalp tween space earth suggestion listed promote et al 29 investigated effect ca addition elevated application development new magnesium alloy temperature mechanical property az series magnesium aerospace field alloy increase added ca al content mg al 2 ca al 2 ca phase precipitated grain bound 2 development mg alloy space application aries interior azx211 alloy posse optimum ten sile property tensile yield strength 25 c lightest metal structural engineering material mag 152 5 4 mpa 95 4 1 mpa respectively chaudry et al nesium alloy show important application prospect trans 51 studied superplasticity az31 magnesium alloy portation energy aerospace field containing 0 5 wt ca addition ca result high specific strength high specific stiffness strong precipitation fine second phase particle grain bound damping vibration reduction good liquid formability aries microstructure stability improved leading shielding electromagnetic radiation easy recycling etc alloy superplasticity alloy 300 c 26 29 however poor high temperature strength series excellent toughness plasticity poor corrosion resistance severely limit wide applica used workpiece high impact load bending tion magnesium alloy 9 30 31 adding alloying ele sistance requirement often used wheel door seat ments effective method solve problem frame equipment dashboard however due poor adding different alloying element al 32 33 thermal stability β mg 17 al 12 phase heat resistance mn 34 35 zn 36 38 si 39 40 ca 29 41 42 li magnesium alloy poor limit application 43 44 9 45 48 etc microstructure struc certain extent rare earth element combined al ture alloy adjusted achieve expected magnesium alloy produce al compound high property melting point beneficial improving high temper j bai yang c wen et al journal magnesium alloy 11 2023 3609 3619 3611 ature performance 52 han et al 34 studied effect resistance alloy β phase content precipitated different ce content microstructure tensile prop aging play decisive role corrosion resistance erties am80 alloy room high temperature alloy 61 mg gd alloy developed ba addition ce alloy consisted α mg β mg 17 al 12 si mg gd nd 62 mg gd nd 63 mg gd al 4 ce microstructure refined sm 64 good performance room temperature amount ce 1 5 wt maximum tensile strength high temperature jdm2 alloy developed shanghai room temperature high temperature 175 9 mpa jiao tong university high strength mg gd alloy 146 mpa respectively 10 wt gd 27 room temperature tensile series containing low aluminum content posse strength yield strength 370 mpa 240 mpa good strength excellent toughness due addition spectively elongation 4 chongqing univer si stable precipitated mg 2 si phase fine disper sity studied mg xgd 0 6zr alloy 2 wt 6 wt sive distribution formed grain boundary creep gd 65 developed high plasticity mg gd alloy resistance alloy improved morphology size moderate strength plasticity 30 gao distribution mg 2 si phase significantly influence al et al 66 studied mechanical property mg gd loys property fine dispersive particle beneficial alloy zn ag element found mechanical improving mechanical property alloy whereas property mg gd alloy peak aging condition coarse mg 2 si particle deteriorate mechanical proper higher mg gd alloy β phase tie alloy 39 refinement uniform distribution strengthening phase precipitated prismatic surface mg 2 si particle key improving property due high solubility α mg matrix alloy chen et al 53 refined grain mg 17 al 12 strong aging hardening ability magnesium alloy con phase as41 magnesium alloy alternating frequency ul taining mg alloy attracted wide attention 48 67 trasonic melting technology eliminating accumulation mg ternary alloy widely studied applied mg2si improving strength alloy due good high temperature strength creep resistance zk series good comprehensive mechanical property 68 currently two kind alloy we43 we54 according astm standard mg zn zr alloy mainly highest degree commercialization devel cludes zk21a zk31 zk40a zk60a zk51a zk61 oped maintain excellent mechanical property etc 54 among zk60 alloy typical superplastic service environment 300 c widely used magnesium alloy good comprehensive property room aerospace power system component 69 70 addition temperature extrusion elongation 17 0 2 zn we43 alloy significantly shorten alloy 55 attracted attention liang et al peak aging time alloy tensile property especially 56 fabricated zk60 mg alloy laser powder bed fusion elongation significantly improved 71 oxida lpbf analyzed effect preheating temperature tion tendency rare earth element greater microstructure mechanical property lpbf treated mg rare earth element high temperature zk60 alloy specimen treated preheating temper lead oxidation burning loss mg alloy ature 180 c exhibit best comprehensive mechanical casting process introduction y2o3 inclusion property yield strength 201 5 mpa ultimate tensile melt affect purity melt order solve

strength 291 7 mpa elongation 14 7 0 8 problem gd element used partially replace ele ment keeping total amount rare earth element 2 2 containing mg alloy unchanged optimized mg 2y 3gd 2nd 0 5zn alloy good casting process performance also room rare earth element magnesium alloy temperature high temperature mechanical property dissolved also form high melting point intermetal equivalent we43 alloy suitable produc lic compound different type distribution mor ing thin walled complex aerospace casting product 72 phologies refined grain improve casting property nd light rare earth element maximum solid mechanical property alloy present widely solubility magnesium reach 3 6 mg nd alloy used mg alloy mg gd mg mg nd mg sm etc solution treatment precipitate series metastable 33 57 58 compared traditional mg al mg zn strengthening phase aging strong aging series alloy developed high performance mg alloy strengthening effect 73 grain cast mg nd binary higher mechanical property relative density alloy often coarse meet service perfor limit solubility gd magnesium extensive mance requirement structural material therefore reaching 24 wt 542 c solution solubility usually necessary add zr refine grain improve decrease decrease temperature reaching mechanical property wang et al 74 studied ef 4 wt 200 c mg gd alloy typical aging strength fect adding 0 5 zr microstructure property ening alloy many nanoscale precipitate formed mg 2 7nd 0 6zn alloy found zn 2 zr 3 nano aging make alloy excellent mechanical property strengthening phase formed alloy solution room temperature high temperature 31 59 60 addi treatment significantly improved hardness tion addition gd element also improves corrosion alloy addition high strength heat resistant mg nd zn 3612 j bai yang c wen et al journal magnesium alloy 11 2023 3609 3619 zr alloy zm6 excellent mechanical property tensile la alloy one commonly used alloy strength 250 mpa elongation 7 corrosion resis mg li alloy used weapon aerospace tance 75 stable high temperature environment density al similar mg al element 250 c widely used defense industry excellent solid solution strengthening effect mg li alloy sm high solid solubility magnesium 76 however ternary mg li al alloy problem low eutectic temperature 542 c maximum solid solubil mechanical property poor thermal stability guo et al ity sm mg 5 8 wt sm good solid 84 studied effect solution treatment mg 9li 6al lution strengthening aging strengthening effect mg alloy result show mgli2al dissolved β li alloy mg sm binary alloy scholar conducted phase alli phase precipitated α mg phase dur lot research aging precipitation process pre ing solid solution meanwhile hardness alloy cipitates mg sm binary alloy xie et al uncovered improved solution treatment al element refines grain diffusional displacive dominated formation mechanism cast mg 14li alloy influence solute element β1 phase mg sm binary alloy 77 li et al 6 found 85 takahiro mineta et al 86 prepared mg li al alloy aging precipitation sequence mg 4sm 0 4zr alloy multi directional forging heat treatment process spe super saturated solid solution β β β1 cific yield strength la143 alloy reached 263 kn kg 1 fcc β bct continuous depth research people tang et al 87 investigated grain boundary decohesion deepened understanding aging process mg mg li al alloy result showed grain boundary sm alloy compared high strength magnesium al precipitation gbps formed al rich ordered phase would loys strength level mg sm binary alloy still low weaken bonding atom grain particle order improve mechanical property rare free zone pfz would formed near gb would earth non rare earth element gd 46 78 zr easily lead local stress exceeding cohesion grain 54 zn 64 yb 47 added mg sm binary boundary resulting intergranular cleavage fracture alloy multi alloying optimize microstructure alloy alloy mechanical property mg sm alloy lz series also common mg li alloy good improved fine grain strengthening solid solution strength chanical property clinical application potential wu et al ening second phase strengthening mao et al 46 studied 88 studied corrosion resistance lz61 kbms kumta effect element microstructure mechani bioresorbable magnesium stent alloy evaluated cal property mg 4sm 0 6zn 0 5zr alloy mechanical simulated dynamic flow environment juxtaposed real property mg 4sm 7y 0 6zn 0 5zr alloy increase ized feasibility ultra high ductility lz61 kbms alloy increase content content reach 6 89 biodegradable airway stent zhou et al 89 studied mi yield strength tensile strength elongation cast crostructure mechanical property lz91 alloy mg 4sm 7y 0 6zn 0 5zr alloy 118 mpa 193 mpa friction stir welding fsw result show stir 10 5 respectively zone alloy composed fine equiaxed α mg β li phase realized optimized strength ductility stir zone zhang et al 90 prepared high strength mg 2 3 superlight mg li alloy 13li 9zn solid solution annealing rolling pure grain boundary supersaturated solid solution obtained mg li alloy attracted much attention due annealing contributes introduction α mg nanoparti advantage high specific strength good damping proper cles ordered b2 nanoparticles β li matrix tie excellent electromagnetic shielding property good subsequent rolling yield strength alloy 380 mpa forming property 79 80

moreover density mg li specific yield strength 251 kn kg 1 yang et al alloy 1 35 1 65 g cm3 1 3 1 4 lighter 91 studied rolling annealing process lz91 alloy traditional mg alloy 81 83 thus mg li series alloy increasing rolling reduction adequate anneal class ultra light alloy effectively promote ing process corrosion resistance alloy continues lightweight process aerospace 3c et al present increase commercial mg li alloy la141 la91 laz933 lt series good thermal stability high mechanical etc microstructure mechanical property mg li property kind alloy great development alloy differ li content change li potential sn element refine grain cast alloy content 5 7 wt mg li alloy α mg phase promote mg li alloy obtain equiaxed grain besides hexagonal crystal structure hcp li content adding sn form dispersed mg 2 sn li 2 mgsn phase 5 7 wt 11 5 wt α mg phase β li phase body good strengthening effect thermal stability centered cubic structure bcc li content mg li alloy zhou et al 92 studied effect extru 11 5 wt mg li alloy β li phase sion mg li al sn alloy result show ex ever low absolute strength poor corrosion resistance trusion abundant dispersed sn rich phase exist alloy mg li alloy greatly limit application therefore massive cid 4 c cid 5 dislocation activated con many researcher consider method alloying de tribute improvement strength plasticity formation strengthen mg li alloy alloy room temperature tensile strength elonga j bai yang c wen et al journal magnesium alloy 11 2023 3609 3619 3613 tion mg 7li 2al 1 5sn alloy reached 324 mpa 11 9 respectively high temperature 423 k tensile strength elongation mg 7li 2al 1 5sn alloy reached 237 mpa 26 7 respectively maurya et al 93 prepared lat971 alloy solution treatment alli phase entirely dis solved matrix alloy dissolved 350 c time existence thermal stable mg 2 sn phase improves hardness tribological property alloy solid solution acikgoz compared effect sn nd ca element mg 8li 2al alloy 94 result show adding sn element best effect fig 2 morphology micro arc oxidation coating thermal control improving alloy mechanical corrosion property magnesium alloy 110 lx series alloy kind alloy good biocompati bility also received extensive attention researcher high electrochemical activity magnesium 103 104 95 ca element improve microstructure many effort made improve corrosion prop chanical property mg li alloy gao et al 96 investi erties magnesium alloy treatment electroplat gated microstructure mechanical property mg 9li ing chemical conversion film oxidation film coating alloy mg 9li 0 3ca alloy extrusion comparative related surface treating process 105 109 however analysis result show adding ca weakens texture something different surface treatment increase proportion drx grain improve magnesium alloy aerospace application compared plasticity alloy addition ca major component used earth satisfy function demand human bone combined mg li alloy play space environment requirement need add thermal important role biomedicine cui et al 97 prepared control electrical conductivity welding function infection resistant coating biomedical mg li ca alloy addition anti corrosion mg 1li 1ca alloy good antibacterial property corro sion resistance ca p sn coating han et al 98 studied 3 1 thermal control coating magnesium alloy corrosion characteristic extruded dual phase mg li ca alloy hank solution extruded mg li ca al thermal control coating commonly used loys undergo overall corrosion corrosion product aerospace functional coating used control jammed micro crack natural oxide film ad temperature ratio solar absorptance αs emit dition proposed new concept pilling bedworth tance ■ surface namely αs ■ electrochemical conver ratio elucidate corrosion mechanism dual phase mg sion coating chemical oxidation micro arc oxidation li ca alloy often employed obtain thermal control coating moreover addition mn 99 nd 100 er 101 110 111 adding iron salt vanadium salt micro 102 element also improve mechan arc oxidation process thermal control film infrared ical property damping property mg li alloy emissivity ■ 0 85 obtained good corrosion example yang et al 99 reported extruded mg 4li resistance successfully applied aerospace fig 2 3al 0 3mn alloy high strength damping property 110 112 113 wang et al 114 prepared several colorized wu et al 101 investigated origin age hardening coating solar absorptance 0 439 0 918 expand age softening mg li zn alloy improved age soft ing application magnesium alloy electrolyte ening mg li alloy adding er element although mg li great influence property coating phosphate alloy research made many achievement critical issue equal silicate silicate greater aluminate mg li alloy still need solved instance cor thermal control performance phosphate coating rosion mechanism mg li alloy thoroughly best higher blackness coating better studied alloying mechanism mg li alloy un absorption coating 115 however corrosion prop clear especially influence different alloying element erties thermal control coating still improved within dual phase matrix 3 2 conductive coating magnesium alloy 3 surface treatment magnesium alloy space application nickel plating technology another common surface treat ment process aerospace obtain good conduc although magnesium offer potential considerable tive

corrosion resistance meet welding need mag weight saving come without drawback nesium alloy 1 2 process corrosion property namely corrosion flammability use wenchang deposition mechanism ni p coating widely studied launch site corrosion magnesium alloy one 116 121 ni p coating formed key problem affecting aerospace application cor coating growth stage also generated initial de rosion resistance magnesium alloy extremely poor due position stage electroless ni p plating 117 typical3614 j bai yang c wen et al journal magnesium alloy 11 2023 3609 3619 fig 3 initial deposition process electroless ni p coating zk60 me20 b alloy 2 growth mechanism ni p plating zk60 me20 cabin adding antibacterial metallic element biopoly given fig 3 initial deposition coating zk60 mer calcium phosphate coating based micro arc oxidation alloy occurs preferentially highly active zn zr precipitate coating improve property 124 compactness mgf 2 film mainly control initial deposition coating me20 alloy coating 4 spacecraft application magnesium alloy property improved ternary ligand system 118 transition layer 119 120 pretreatment 121 1950s 1960s united state carried bi layer coating formed composed micro arc oxida lot research magnesium lithium alloy used tion coating mao electroless plated ni p coating secondary structural material bracket bushing corrosion property improved 2 8 time 122 beam structure aerospace field viet union also developed ma21 brand lunar 3 3 functional surface treatment magnesium alloy lander fig 4 56 126 127 magnesium alloy component also used satel coating special property wear anti lites spacecraft china beijing spacecraft manufac corrosion et al may also used aerospace 106 123 turing factory co ltd solved anti corrosion treatment 125 sun et al 123 fabricates fe based amorphous coat machining welding technology problem large mag ing wear property 170 time higher nesium alloy surface realized application bare la141 magnesium alloy substrate may large magnesium alloy structure multiple spacecraft applicable aerospace structure mechanism wang g04 magnesium alloy developed institute metal et al prepares super hydrophobic corrosion resistant chinese academy science successfully used coating thin thickness 125 may used inside electric cabinet shenzhou vi manned space manned cabin high bactericidal property low vac craft reducing weight 13 kg national en uum performance also expected used manned gineering research center light alloy precision form j bai yang c wen et al journal magnesium alloy 11 2023 3609 3619 3615 fig 6 composition structure b panel panel extension satellite 131 fig 4 mg alloy developed lockheed satellite gyro scope installation frame plate vibration diaphragm load transfer joint corner tray installing electronic device drawer partition although strong aluminum weight ba microwave device installation frame respectively si magnesium approximately 30 lighter application magnesium electronic chassis result weight saving approximately 25 aluminum containing plating magnesium surface 8 improvement magnesium alloy toughness corrosion resistance forming performance etc magnesium gradually considered use product bracket storage tank heat pipe honeycomb panel skin embed ded part 14 133 134 however lightweight structure cause lowering stiffness thus way weight saving structure flexible value stiffness must kept weight saving moreover property need considered used seat structure flammability property needed con fig 5 satellite bracket sidered two type magnesium alloy investigated separate test result showed magnesium al loy we43 well performing poor performing ing shanghai jiao tong university prepared variety az31 respectively 135 136 aerospace component meet operating require magnesium alloy may also used structural plate ments satellite mar probe achieve weight development magnesium alloy skin hon reduction effect 20 30 fig 5 128 130 eycomb weight structural plate effectively reduced magnesium foam studied foam 4 1 application structure material spacecraft 50 wt carbamide sintered 630 c density platform 0 61 g cm3 porosity 64 7 compressive strength 5 mpa 137 chongqing university independently developed structural material main body satellite new type high strength rare earth magnesium alloy account main weight satellite platform trial produced component certain type spacecraft used magnesium structural material instead aluminum low pressure casting 138 engineering application alloy traditional aerospace metal structural material research large complex magnesium alloy component reduce weight structure obviously panel panel also developed successfully realized shanghai extension satellite shown fig 6 test model made aerospace precision machinery research institute car aluminum 700 g moreover calculated ried research engineering application magnesium weight design made magnesium le alloy large size complex component recent year 500 g 131 developed high performance heat resistant casting electronic chassis one widely used magne vw63z realized batch engineering application sium alloy typical electronic package spacecraft appli vw63z magnesium alloy aircraft high cation consists printed

circuit board pcbs electronic chanical property engineering condition large component supporting structure trade melting volume slow cooling sand meet weight strength stiffness radiation electro magnetic index room temperature tensile strength casting terference emi protection magnesium always used body 300 mpa high temperature tensile strength supporting structure shown fig 7 8 132 280 mpa 139 3616 j bai yang c wen et al journal magnesium alloy 11 2023 3609 3619 fig 7 application magnesium structure electronic package b random vibration test c 132 fig 8 large size magnesium alloy product developed shanghai space flight precision machinery institute fig 10 scientific payload ce 5 142 magnesium alloy effective load reduce weight optimize performance antenna typical payload often used various space communication system antenna consists fig 9 disturbance free payload architecture spacecraft 140 conical corrugated horn waveguide feed generating high frequency electromagnetic radiation shown fig 11 4 2 application spacecraft payload 143 145 perform successfully launch orbit space antenna must strong stiff lightweight payload important part satellite small thermal distortion 146 specific strength important influence performance satel specific rigidity elastic modulus good high low tem lite typical payload layout load type shown perature toughness magnesium tried use fig 9 fig 10 respectively 140 142 application waveguide antenna 147 148 li et al 147 pointedj bai yang c wen et al journal magnesium alloy 11 2023 3609 3619 3617 fig 12 fabricated 175 mm spherical magnesium alloy mirror left right panel show mirror surface backside mirror fig 11 metallic corrugated horn antenna corrugated horn feed b respectively conventional design offset mirror antenna courtesy i reshet nev company c 143 144 advanced metal hydride studied heating cool table 1 ing cabin electric vehicle 156 key parameter comparison magnesium lithium metal fuel cell one important energy set rechargeable metal ion battery 151 155 may applied aerospace hydrogen storage ability information lithium magnesium key problem lightweight space application market price k ton 64 8 2 7 fuel cell hydrogen storage magnesium compound volumetric capacity mah cm 3 2061 3833 lieved one promising hydrogen storage tech gravimetric capacity mah g 1 3884 2206 nologies high efficiency low risk low cost 157 158 anode potential versus v 3 04 2 36 stability air yes hydrogen capacity reach 14 9 wt mass dendrite growth yes 145 147 kg cm 3 volume significant weight atomic weight 6 9 24 3 advantage current cylinder hydrogen storage thus cationic radius nm 0 068 0 065 promising hydrogen storage material space fuel cell application weight antenna part could reduced declaration competing interest 20 considering structure strength tenna product based magnesium alloy would author declare conflict interest widely used aerospace field f zhou z x xu regarding publication article demonstrated seven month ground environment one year space environment test gold reference plated magnesium alloy layer communication satellite omnidirectional antenna good use signal 1 l chen ye wang zhou suo q deng f zhao q wang returned ground clear normal 149 150 mater charact 182 2021 111535 111543 2 l feng w zhang c wen z li j f li cheng j bai magnesium alloy also designed fabricated ap q x cui l g zhang trans nonferr met soc china 31 8 2021 plication space borne telescope optic instrument 2307 2322 175 mm magnesium alloy mirror spherical mirror 3 l feng c wen j li li cheng j bai q cui mater re surface backside hexagonal cutout structure reduce express 6 5 2019 056548 056560 mass mirror shown fig 12 151 4 r min z chen wang z deng zhang deng j proteom 237 2021 104144 5 r verker bolker carmiel gouzman e grossman 4 3 application energy subsystem spacecraft k minton remaury acta astronaut 173 2020 333 343 6 maclay mcknight j space saf eng 8 1 2021 93 97 7 f xu x jia w lu c zhou guo j fei c yang acta astronaut magnesium alloy good energy storage electri 151 2018 585 594 cal property widely studied energy materi 8 f winterberg acta astronaut 162 2019 373 375 al used energy subsystem spacecraft 9 j meier j caris luo j magnes alloy 10 6 2022 152 154 1401 1427 mg lightweight metal 1 74 g cm 3 density yield 10 h l shi c xu x hu w gan k wu x j wang j magnes alloy 10 8 2022 2009 2024 ing theoretical volumetric capacity magnesium 3833 11 j ni l jin j zeng j li f l wang f h wang dong j dong h cm 3 twice lithium 2061 h cm 3 j magnes alloy 11 1 2023 1 14 property compared li ion battery listed 12 l sun b f fan wang z wang j magnes alloy 10 table 1 151 155 according table data rechargeable 10 2022 2875 2888 magnesium battery high safety energy storage technology 13 l liu x chen f pan j magnes alloy 9 6 2021 1906 1921 14 x l zhang g k yu w b zou ji z liu j l cheng china may potential application aerospace magnesium foundry 15 6 2018 418 421 also used energy carrier renewable ther 15 k bond b goddard r c singleterry bilbao león acta mal energy storage concept thermal battery based astronaut 165 2019 68 95 3618 j bai yang c wen et al journal magnesium alloy 11 2023 3609 3619 16 smirnova acta astronaut 103 2014 250 256 53 x chen z yin q le ning f yu int j

metalcast 16 1 2021 17 labukas j n f lander l blohm v rodriguez santiago 474 480 parker report u army re 2016 54 x gao h yan j chen w xia b su x zhou heat treat met 18 j hu c hu che x zhu j yang li c li acta astronaut 44 1 2019 81 85 184 2021 274 285 55 l l chang x j su j l qin mater lett 325 2022 132666 19 li c hu x zhu j hu x hu c li cai acta astronaut 56 j liang wu z lei chen x zhang b li jiang chen 155 2019 334 349 mater charact 2022 112361 20 e shafirovich salomon gökalp acta astronaut 59 8 11 57 b jiang w liu l xiao h dong n zhang r cheng j song 2006 710 716 zhang f pan aerospace 36 2 2019 22 30 shanghai 21 mccallum c domeneghetti j schwartz e k mullen 58 j song j chen x xiong x peng chen f pan j magnes zema f cámara c mccammon j ganguly geochim co alloy 10 4 2022 863 898 mochim acta 70 24 2006 6068 6078 59 c tang g zuo z li x sun q li mater rep 32 11 2018 22 z naser acta astronaut 155 2019 264 273 3760 3767 23 mottaghi h benaroya j aerosp eng 28 1 2015 705 747 60 j wang li h x li z k n zhao c l yang j zhang 24 r spark acta astronaut 17 10 1988 1093 1097 j magnes alloy 9 5 2021 1632 1643 25 delgado magnesium based combustion synthesis advanced 61 l yuan w shi w jiang z zhao mater sci eng 658 material energy space application university texas 2016 339 347 el paso 2016 p 341 62 f qi x zhang g wu w liu x w ding mater sci eng 26 rakshith p seenuvasaperumal j magnes alloy 9 5 2021 813 2021 141172 1692 1714 63 l guan deng luo x guo c tang mater sci eng 804 27 g wu c wang sun w ding j magnes alloy 9 1 2021 2021 140736 1 20 64 yuan c j zhao h yang song b lei x qian z dong 28 yang x xiong j chen x peng chen f pan j magnes q li b jiang f pan j mater re technol 15 2021 2518 alloy 9 3 2021 705 747 2528 29 gokalp incesu int j metalcast 17 2 2022 1402 1412 65 b hu j deng c zhao j f wang f pan trans nonferr met 30 b li j dong z zhang j f nie l bourgeois l peng mater de soc china 21 4 2011 732 738 116 2017 419 426 66 x gao j f nie scr mater 58 8 2008 619 622 31 h liu gao j z liu zhu wang j f nie acta mater 67 w yang g f quan b ji f wan h zhou j zheng yin j 61 2 2013 453 466 magnes alloy 10 1 2022 195 208 32 h liao zhan c li z j du j magnes alloy 9 4 2021 68 x tong g wu l zhang wang w liu w ding j magnes 1211 1219 alloy 10 1 2022 180 194 33 z z jin zha q wang c wang c wang h l jia 69 j li r chen w ke j magnes alloy 1 4 2013 346 351 h wang j magnes alloy 10 5 2022 1191 1206 70 h kang z h huang c wang h yan r chen j c huang 34 q han wu j shi c li w li c liu c lan j ordnance j magnes alloy 8 1 2020 103 110 equip eng 43 2022 355 71 h kang wu r chen e h han j magnes alloy 2 2 35 liu w l cheng x j gu h liu z q cui l f wang 2014 109 115 h x wang j magnes alloy 9 5 2021 1656 1668 72 k luo l zhang g wu w liu w ding j magnes alloy 7 2 36 li hot work technol 49 15 2020 83 2019 345 354 37 w j yin f briffod shiraiwa enoki j magnes alloy 10 8 73 c ha j bohlen x zhou h g brokmeier k u kainer n schell 2022 2158 2172 letzig yi mater charact 175 2021 111044 38 q zeng b zhang k n li zhuang j h li j yuan yin 74 w z wang wu r chen qi h q ye z q yang j alloy j magnes alloy 11 2 2023 533 542 compd 832 2020 155016 39 c li j shaanxi univ technol nat sci ed 30 5 2014 277 291 75 gao c liu fu j jin x shu gao surf coat technol 40 w p yang wang h b cui g x fan x f guo j magnes alloy 204 21 22 2010 3629 3635 10 11 2022 3234 3249 76 k guan r j zhang r wu q yang j meng j magnes 41 c w yu x pi guitton j magnes alloy 8 4 2020 alloy 9 3 2021 1098 1109 1084 1089 77 h xie x zhao j jiang j bai li h pan x pang h li ren 42 r sahu kumar u chakkingal j magnes alloy 10 8 g qin mater charact 174 2021 163732 163736 2022 2094 2117 78 h mao x bai tian z yin wang h xu p sun ge spec 43 x yu j cui c liu f yuan guo deng chem eng sci 229 cast nonferr alloy 4 2 2022 194 199 2021 116019 116026 79 guo g quan celikin l ren zhan l fan h pan j 44 c li h huang j magnes alloy 9 2 2021 569 580 magnes alloy 10 7 2022 1930 1940 45 wang zhang zhong q dai j hua luo g hu j xu 80 b b yang c shi zhang j j hu j w teng j cui p li b jiang f pan j mater re technol 20 2022 3735 3749 chiba j magnes alloy 10 10 2022 2775 2787 46 h xie w lou x zhao li h pan n xiao h li j bai ren 81 j wang jin r wu wang b qian j zhang l hou j alloy g qin mater charact 170 2020 132666 132669 compd 927 2022 1816 1825 47 zhang q yang b li k guan n wang b jiang c sun 82 xin tang f ji l cui b x lin x tian h hou zhao zhang x li z cao j meng j alloy compd 805 2019 ferry acta mater 239 2022 285 290 811 821 83 c q li x liu l j dong b q shi tang dong z r zhang 48 j zhang liu r wu l hou zhang j magnes alloy 6 3 mater lett 301 2021 4749 4762 2018 277 291 84 x guo r wu j zhang b liu zhang mater de 53 2014 49 liu li q zhu h zhang x qi j wang p jin x zeng j 528 533 magnes alloy 9 2 2021 499 504 85 zeng b jiang r li h yin al ezzi metal 7 5 2017 50 c cui w c zhang w z chen j x chen j b hou j 143844 143854 magnes alloy 10 10 2022 2745 2760 86 mineta k hasegawa h sato mater sci eng 773 2020 51 u chaudry k hamad g ko mater sci eng 815 2021 254 265 140874 87 tang xin luo f ji c li feng lan j alloy compd 52 luo int mater rev 49 1 2004 13 30 902 2022 69 82 j bai yang c wen et al journal magnesium alloy 11 2023 3609 3619 3619 88 j wu l j mady roy aral b lee f zheng catalin 122 c chen jian c h lu c lee l aktug ger j chun w r wagner k yang h e trejo bittar chi p n kumta mater re technol 9 6 2020

13902 13913 commun biol 3 1 2020 787 123 j sun r yang l xie w r wang b li l wang h x li 89 zhou morisada h fujii j wang mater sci eng 773 j zhang j zhang surf coat technol 426 2021 1 5 2020 11763 11777 124 z lin wang x yu x sun h yang j alloy compd 879 2021 90 zhang c du r wu h jia q wu j zhang l hou mater sci 160453 160461 eng 850 2022 111972 111981 125 g wang song qiao j cheng h liu j jiang x 91 l n yang g zhou f j ren h j deng g b wei x peng j magnes alloy 11 4 2023 1422 1439 trans nonferr met soc china 30 7 2020 1816 1825 126 f czerwinski corros sci 86 2014 1 16 92 g zhou yang h zhang f hu x zhang c wen w xie 127 b xue z b xu x zhang g li q w huo x zhou foundry b jiang x peng f pan j mater sci technol 103 2022 186 196 technology 43 04 2022 290 294 93 r maurya mittal k balani j mater re technol 9 3 2020 128 w ding g wu z li l xiao chen aerospace 36 2 2019 4749 4762 1 8 shanghai 94 acikgoz c kurnaz int j metalcast 17 3 2022 1580 1595 129 g h wu w j ding manned spacefl22 3 2016 281 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