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http pub ac org journal acsodf review overview various additive manufacturing technology material electrochemical energy conversion application bulut hu ner murat k■st■ su leyman uysal il ayda nur uzgören emre zdog yakup ogu n su zen nesrin demir mehmet fatih kaya citethis acsomega2022 7 40638 40658 readonline access metric articlerecommendations abstract additive manufacturing technology many advantage design flexibility minimal waste manufacturing complex structure cheaper production rapid prototyping technology widely used many field includinghealth energy art design aircraft andautomotive sector inthemanufacturingprocessof3d printedproducts itis possible produce different object distinctive filament powder material using various production technology cover several 3d printing technique fused deposition modeling fdm inkjet printing selective laser melting slm andstereolithography sla thepresentreviewprovidesanextensiveoverviewoftherecentprogressin3dprintingmethodsfor electrochemicalfields adetailedreviewofpolymericandmetallic3dprintingmaterialsandtheircorrespondingprintingmethods electrode also presented finally paper comprehensively discus main benefit drawback electrode production method energy conversion system 1 introduction producesmallvolumeparts maybedecreasedsignificantly 7 9 whentheindustrialrevolutionisconsidered animprovement increasing population growth rapid industrialization require new research study meet energy demand 1 expected manufacturing process product reason three dimensional 3d printingtechnology knownas due people high growing energy need clean method account basis industrial environmentally friendly renewable energy technology may revolution 4 0 among new production technique provide sustainable solution reduce greenhouse gas technology provides rapid production part adding emission many researcher turned search clean object layer layer computer aided 3d geometry environmentally friendly renewable energy source interestinuseofsolarenergy 2windenergy 3andenergyfrom model without constraint traditional machining biomass4 application increasing day day develop forging casting process among rapid production method technology recently paved way ment renewable energy system promising improvement design industrial application solutionofthemostsignificanttasks likeimprovingtheenergy rapidproductionofcomponents avarietyofammethodsand supply security biofuel economy solving local energy material given table 1 water supply problem raising living standard employment level local population 5 6 however high technology great capacity decrease material waste production stage product cost one biggest obstacle common use toreduceenergyconsumptionbecauseithasbeendetermined thesesystems theproblemofaccesstorawmaterials whichis significant decrease 27 global among reason high cost may provide long term energy demand widespreaduse technology 9 solution sustainable development renewable energy recent time technology widely used technology thewidespreaduseofnewtechnologies suchas may contribute reduce carbon footprint method claimed green technology great received august9 2022 potential increase material efficiency reduce life cycle accepted october20 2022 impact reduce need special tool published november3 2022 manufacture part also provides faster production time saving compared traditional method fore energy consumption required time cost 2022theauthors publishedby americanchemicalsociety http doi org 10 1021 acsomega 2c05096 40638 acsomega2022 7 40638 40658acs omega http pub ac org journal acsodf review table 1 various technique material process material method ref directedenergy metal lasermetaldeposition lmd 10 12 deposition materialextrusion thermoplasticpolymers fuseddepositionmodeling fdm 13 15 powderbedfusion plastic metalsandpolymers ceramicpowders electronbeammelting ebm selectivelasermelting slm 16 18 selectivelasersintering sl materialjetting polymer multijetmodeling mjm 19 20 binderjetting polymer metalsandfoundrysands powderbedandinkjethead3dprinting pbih plaster based3d 21 23 printing pp inkjetbioprinting biomaterialsandhumancells inkjetbioprinting 24 25 sheetlamination polymer metalsandceramics laminatedobjectmanufacturing lom ultrasonicadditive 26 27 manufacturing uam vatpolymerization acrylate epoxides photoresins photocurablematerials photopolymerization digitallightprocessing dlp continuous 28 31 vp polymersandceramics liquidinterfaceproduction clip different energy sector enhance performance discussed future perspective presented new increaseenergyefficiencyinthe3dprintingofproducts ithas generation energy conversion application research especially accepted one new generation development r study solution energy storage energy conversion electro 2 material used 3d printing method chemical application example traditional method disadvantage produce flow channel 2 1 polymer based material polymer preferred electrode bipolar plate energy application theam methoddue totheireasier productionandlower cost machining method term cost comparedtothoseofotherbuildingmaterials infigure1 geometricalstructures therefore theammethodhasrecently become lead production system term design freedom material saving easy production complex structure 32 33 first application photo polymerization method 3d printing method method introduced 1980s hideo kodama developed method creating 3d object curing photocuringpolymerunderultraviolet uv light itisknown stereolithography sla method 34 lamination method realized stacking material afteralayercontourdefinitionisobtainedwithcuttingtoolsin 3d printing process lamination method knownaslaminatedobjectfabrication lom wasdiscovered athelisys inc inthelate1980s inthismethod firstalayerof materialisloadedontothetableandthentheprofileiscreated bycuttingwithalaserorblade 35aftertheremainingmaterial figure 1 material method according amount removed second layer loaded top first layer material consumptionby weight 2014 reprinted permission according type material paper metal ref 40 copyright2015nova science publisher plastic layer obtained sticking previous one using adhesive welding method 36 another method distribution consumed polymeric material extrusion based3dprintingprocessthatproducesproductsby methodin2014canbeseen plasticmaterialsrepresent99 directly depositing material help nozzle industry involved development series pretreatments liquefaction process technique structural mechanical compound metal 39 known fused deposition modeling fdm creates intheammethod polymershavethepotentialtorepresent 3d printed object using polymer material explored manymoreapplicationthanmetalsinmanyfieldsfromenergy scott crump 1989 37 developing 3d printing sustainable application health biomedical technologyhasprovidedrapidprototyping whichiscriticalfor filamentsusedinthefdmmethodrepresentthelargestpartof micro macrostructure design energy application industry although several polymeric material because3dprintingrepresentsanewmanufacturingtechnique available vary process 3d printing production energy conversion storage depending method mechanical property technology production functional material polymer acrylonitrile styrene butadiene ab 41 energy application among advantage technolo polycarbonate pc 42 polylactic acid pla 43 polystyrene gy offer unique ability increase specific performance p 44 polyamide pa 45 andpolyurethane pu 46 used perunitmassandvolumeinthemanufactureofenergydevices method material used low complex shape 38 performance component prototype design study fabrication 3d printed product using time polymer polyether ether ketone peek polymer based metal powder based material polyphenylsulfone ppsu polyetherimide pei poly electrochemical application coating study phenylene sulfide pps used method due 3d printed product different geometry extensively heat chemical resistance 47 49 reason 40639 http doi org 10 1021 acsomega 2c05096 acsomega2022 7 40638 40658acs omega http pub ac org journal acsodf review interestinthismethodisincreasingdaybydaytoenhancethe atures 210 250 c depending mechanical property composite nanocomposite application comparison nozzle build plate material acquire new function like thermal temperature value widely used material electrical conductivity commercially available polymer 50 fdm method listed table 2 one method fdm preferred methodduetoitslowproductioncosts withtheexpirationof table2 valuesoftemperatureusedintheapplicationsof stratasys fdm patent 2009 spread fdm polymeric material machine production 3d printed product increased increase method may accelerate thermoplastic nozzletemperature build platetemperature material c c ref growth manufacturing technology product development new smart material nanocomposites pla 200 210 60 biomaterials 37 51 energy conversion application pla ab 225 260 80 90 ab based filament common thermoplastic 52 petg pet 225 245 85 60 2 1 1 polylactic acid thermoplastic pla thermo pp 205 220 85 100 plastic material may obtained renewable biomass pc 260 280 110 resource starch corn starch sugar cane tapioca root belongs category biodegradable trap heat printing area 3d printed polymer 53 completely biocompostable property product ab filament 3d printer closed able reduce solid waste disposal problem pla based side ab filament affected polymer preferred mostly developing bioplastics temperaturechangeeasily allfilamentsmayemitodorsduring industry due easy availability low cost 54 55 pla printing process although pla filament emit material mechanical property like tensile strength foul odor plant based property ab filament impact strength lower polypropylene ppy poly emit distinct odor 61 62 thanks diversity ethylene terephthalate pet poly ethylene tereph industrial application important opportunity thalate glycol petg basedpolymers comparedtoconven improve property ab open new area tional polymer like ppy polystyrene p polyethylene application new application area may increase compet pe pla higher mechanical tensile bending itiveness polymeric based 3d printing material strength semicrystalline amorphous structure moreover also thermoplastic petg melting temperature pla may change 55 180 pet andppythatcanbeusedin3dprintingprocess petg c thermal feature pla exhibit structural high strength resistance low cost material difference according molecular weight utilized many field medical automotive composition 56 concluded pla good aviation building electrical electronic application 52 stiffness tensile strength gas permeability comparable hand pet one recycled polymeric synthetic polymer one material high volume commercial consumer applica promising material replace petroleum based polymer tionsbecauseitiswidelyusedinplasticpackagingapplications thepackagingindustrysector moreover inthefutureresearch recycling material beverage industry 63 ppy pla low cost material due biodegradable another polymer material gained popularity propertiesandsimpleproductionofcomponentsforindustrial quickly lowest density among application although nowadays higher production commercial plastic 64 costthanpetroleum derivedplastics pla basedpolymersmay 2 2 additive manufacturing polymeric structure used many different practical application energy conversion application rapid prototyping agriculture packaging food packaging medical biomedical transforming complex structure product reducing industry energy sector automotive industry printing error improving mechanical property 2 1 2 acrylonitrile styrene butadiene thermoplastic main factor may increased high molecular mass styrene acrylonitrile copolymer developmentofamtechnologies fdmandthemultijetfusion butadiene acrylonitrile copolymer used fabricate mjf method commonly used 3d printing bullet proof polymer board final year world polymer based filament 65 fdm method thermo warii thesepolymershavehighimpactstrengthduetotheir plastic polymer filament used 3d printing designed low thermoplastic flow property ab product product due thermoplastic property polymer systematic polymerization acrylonitrile butadiene filament provides important advantage method styrene also many property good thermal allows fusing together 3d printing stability high resistance high toughness even cold solidifies room temperature 3d printing process condition hardness important feature ab finished layerthickness width fillingrate andprintingspeed polymer low cost high strength low thermal filament main parameter affect expansion moreover development method like mechanical property formation part low cost injection molding graft polymerization increased high speed simplicity production step main interest ab plastic ab also may us many field advantage fdm method however poor likedesign fashion toy andmodernart 57 58thewidespread mechanical property poor surface quality limited useoffdmtechniqueshasbeenincreasedwiththeutilization number material main disadvantage 66 67 ab polymer 3d printer 59 comparison pla figure 2 production step 3d printed model using filament ab polymer filament require higher nozzle fdm method seen bed temperature require wide range bed asseeninfigure2 thefirststepof3dprintingistocreatea temperature 80 110 c nozzle temper 3d object using computer aided design cad software 40640 http doi org 10 1021 acsomega 2c05096 acsomega2022 7 40638 40658acs omega http pub ac org journal acsodf review figure2 productionstepsof3dprintedproductswiththefdmmethod 3dcadmodel b conversionstlfiletodesignedsample c slicingprocess 3dprinting e 3dprinted product second step convert 3d object stl standard carbon black conductive pla filament conductive triangle language file format third step separate plafilamentisusedinmanyfields suchaslow voltagecircuit layersoftheobjectconvertedtostlformatintolayerswitha application touch sensor area touch screen pen slicing program fourth step set different printing addition theproto pastaplafilamenthasavolumeresistance parameter suchasthenumberoflayers thickness andfillrate of30ω cmfor3dprintedpartsperpendiculartothefilament oftheobjects andthenitissenttothe3dprintertocreatethe layer 71 metal based conductive pla filament produced product method generally polyamide 12 pa12 multi3d company commercially available polyamide 11 pa11 glass beaded pa12 polymer electrifi conductive pla filament conductive pla powder used pa12 widely used multijet fusion filamenthasabrowncolorandaverylowvolumeresistanceof mjf method infigure3 thestagesofthemjfmethodcan 0 006 ω cm filament used many field seen electricalcircuit electrochemical andsensorapplications 72 literature proto pasta black magic electrifi conductive pla filament used widely 3d printingmethodsinelectrochemicalapplications forexample vernardouetal 73preparedelectrodesforlithium ionbatteries using 3d printing graphene based pla filament fabricated electrode 3d printer dual extruder used conductive pla filament resistance 0 6 ω cm also investigated electro chemicalpropertiesofthe3dprintedelectrodesina1mlicl figure 3 demonstration mjf method involving aqueous solution concluded graphene based application polymer powder layer reprinted permission conductive pla filament used high performance fromref 68 copyright2018 elsevier electrodematerials 74 75inrecentyears theinvestigationof3d printing method electrochemical application area increased 76 79 electrode electrochemical energy con method theproductionstepis startedbydeposition versionreactionshavebeenobtainedas3dprintedwithmetal ofalayerofpapowderontheplate ablackinkfusingagentis polymer based material time 3d printing applied powder bed contains infrared absorbing technology provided new approach material agent moreover substance added powder bed production variety application low prevent fusion particle enhance resolution cost ba etal 80preparedthe3dprintedanodeelectrodesfor method polymer heating obtained melting microbial electrolysis cell using conductive pla filament agent absorbs ir radiation transforms thermal copper basedelectrififilament toincreasethemasstransfer energy allows material fuse passing planar inside cell electrode designed different infrared ray powder bed form layer geometry rod 1 cycledspiral 2 cycledspiral 3 cycledspiral build plate move form 3d part process repeated layer layer production 68 4 cycled spiral produced using 3d printing 2 2 1 conductive polymer based material electro method used cheese whey wastewater electrolyte chemicalapplications plaandabspolymerthermoplastics two chamber microbial electrolysis cell different shaped 3d printed electrode perform electrochemical electrical conductivity increased addition various conductive material conductive material 3d analysis interpreted organic content printingareusuallyobtainedusingmetal carbon andpolymer waste electrode geometry increase microbial composite addition different conductive carbon electrolysis performance hydrogen production material graphene carbon black nanofibers literature many report 3d printable polymer material carbon nanotube different way composite material gain havebeenpresentedusingpla graphenefilaments 81 82abs conductive property 69 example graphene based pla carbon black filament 83 polypropylene carbon black filum filament produced black magic 3d bm ments 84 polybutylene terephthalate carbon nanotube gra commercially available conductive graphene pla phene 85 carbon nanofiber graphite polystyrene compo filament black colored bm pla filament 0 6 ω site filament 86 production 3d printed electrode cmvolumeresistivityvalue thisconductiveplafilamenthas usingthermoplasticmaterials carbonnanotube graphene mechanical strength higher nonconductive pla carbon black material mixed increase electrical ab filament thus conductive graphene pla filament conductivity electrode 87 88 however electrochemical utilizedin many applicationareas sensor printed physical deposition technique required improve circuit telecommunication medical device aerospace conductivity desired level increase automotive sector 70 carbon based pla filament electrochemical activity conductivity electrode produced proto pasta commercially available deposition electrochemically active nanomaterials 40641 http doi org 10 1021 acsomega 2c05096 acsomega2022 7 40638 40658acs omega http pub ac org journal acsodf review table 3 3d printed electrode electrochemical coating application 3dprintingmethod filament applicationfield coatingmaterial coatingprocess ref fdm graphene plafilament electrode nickel copper electrochemical 78 fdm conductivecarbon plafilament electrode nickel copper electrochemical 95 fdm blackmagicplafilament electrode gold electrochemical 89 fdm blackmagicplafilament electrode nickel platinum electrochemical 96 fdm blackmagicplafilament electrode nickel iron electrochemical 99 fdm conductivecarbon plafilament electrode nickel electrochemical 100 fdm electrifiplafilament electrode copper electrochemical 101 fdm blackmagicplafilament graphene placompositeelectrode bismuth electrochemical 102 fdm graphene plafilament electrode nickel electrochemical 103 fdm proto pastaplafilament battery electrode zinc copper electrochemical 104 fdm absresin compositeelectrode copper electrochemical 105 fdm blackmagicplafilament electrode molybdenumsulfide electrochemical 106 graphene polypyrene 89 well noble metal 90 reaction oer andhydrogenevolutionreaction using moreover commercially available pla ab filament fdm method produced graphene pla electrode 3d printing technology provided advantage commercially available conductive filament manufacturing electrode without need calledblackmagic theystatedthatthe3dprintedgraphene extrusionstep forexample binhamzahetal 91produced3d pla electrode exhibited low catalytic activity printedabs blackcarbonelectrodesbythefdmmethodand poor electrical conductivity production 3d printed investigatedtheirelectrochemicalbehavior theyprepared3d conductive material currently limited research level printed electrode horizontal vertical direction application especially conductive polymeric performance electrode compared filament gap improving electrical observed vertically printed 3d printed electrode conductive property another study hu ner et al 96 showedamoreadvancedcurrentthanthehorizontallyprinted prepared graphene based 3d printed electrode using 3d electrode moreover concluded conductive printing method co deposited different surface area 3d printed electrode equal molar ratio ni pt examine feature capacitive measurement electrochemical activation gra electrode alkaline medium electrochemical phene polymer based filament also another issue measurementsofthepreparedelectrodes theydeterminedthat electrochemical energy conversion study 92 thanks uncoated graphene based electrode least activation technique amount pla reduced kinetic activity alkaline medium however stated improvetheelectrode sconductivemedia joa oetal 93studied activity increased coated electrode use 3d printed electrode fuel bioethanol quality withniandptelements conductivegraphene based carbon controlusingthefdmmethod theelectrodeswereprepared based metal based polymeric filament could allow mixture carbon black proto pasta pla filament production novel 3d printed electrode electrochemical theelectrodeswereproducedinhollowcubesof4cm 4cm application toincreasetheelectricalconductivityandkinetic wall thickness 2 mm prior using electrode activity 3d printed electrode necessary adjust theyappliedapolishingprocesstopreventpossibleleaks printing parameter electrochemical coating also performed optimized chemical electrochemical pro electrode surface thin film 3d printed electrode also cessing step electrochemical cell nonconductive used electrochemical analysis replacing polymericmaterialisremovedfromthesurfaceoftheworking traditional carbon electrode example akshay kumar et electrode provide higher conductive layer work al 97 prepared electrode 3d printing used material concluded 3d printed cb pla electrode high catalytic efficiency improve electrochemical exhibited good conductivity low current chemical performance used easy cost effective dip electrochemical surface treatment thus successfully coatingtechniqueforthecoatingoftheelectrodes toexamine completed fuel bioethanol analysis improve thecatalyticandkineticactivitiesof the3dprintedelectrodes conductivity pla based conductive filament electro reaction electrode coated different chemical cu coating also useful method 94 application transitionmetals suchasws wse mo andmose 2 2 2 2 cu coating provide opportunity using different concluded using dip coated 3d printed electrode shaped geometry design electrode capacitor sensor energy conversion application improved surface proper electrical circuit hu ner et al 95 prepared electrode tie moreover also stated surface 3d 3d printing method using carbon conductive pla filament printed electrode coated various transition toincreasetheconductivityandelectrochemicalperformance noble metal may used electrochemical electrode ni cu binary coating different volume application future electronics sensor energy storage ratio deposited electrochemically 3d printed system siowwoon et al 98 prepared 3d printed nanocarbon electrode according result kinetic performance pla electrode mo coated photoassisted electro 2 ofni cu coated3dprintedelectrodesincreasedcomparedto catalytic using atomic layer deposition ald theuncoated3dprintedelectrode moreover theydetermined method optimized ald process low temperature resistance value ni cu coated 3d printed thecoatingofmos onthe3dprintednanocarbonelectrodes 2 electrodesdecreasedby99 5 inanotherstudy fosteretal 81 changed 38 900 ald cycle produced 3d printed electrode oxygen evolution performed low deposition temperature explained 40642 http doi org 10 1021 acsomega 2c05096 acsomega2022 7 40638 40658acs omega http pub ac org journal acsodf review prepared electrode higher electrocatalytic 3d printed novel electrode act electrochemical activity reaching overpotential 480 mv lower coating application 109 3d printed electrode able explore cycle moreover stated ald deposition novel area electrochemical device contributes technique suitable produce complex structure new application electrode may designed ambiguous area like 3d printed object list electro extraordinary geometry battery performance chemicalcoatingsofvariousmetalsontheelectrodesprepared traditional geometry cylindrical planar button etc 3d printing method given table 3 perform well kim et al 107 produced 3d printed object using three 2 3 metal based material metal based material different commercially available thermoplastic based conduc higher demand polymeric based conductive pla tive filament electrifi black magic proto pasta filament electrochemical energy conversion application electrochemically coated 3d printed object due higher conductivity value material like ti 110 copper 5 15 30 60 min investigated ti al v alloy 111 112 fe mn alloy 113 bronze 114 al6061 115 6 4 electricalpropertiesofthe3dprintedobjectsafterthecopper al3003 116 nickel 117 stainless steel s 118 120 copper121 coating process according result 3d printed areusedinametal based3dprintingmethod inthismethod sample prepared using electrifi filament coated metal powder particle size ranging 50 100 µm copper 60 min best electrode also claimed areutilized theuseofpowderswithsmallparticlesizesallows copper coating reduces electrical resistance theformationofhomogeneouslayers whentheparticlesizeis increase thermal stability current density decreased minimum compressible layer thickness value electrode do santos et al 99 prepared 3d printed pla reduced powderswithlargeparticlesizescauseuncontrollable graphene basedelectrodesforoerreactionsandperformeda porosity produced part 122 binder liquid glue coatingprocessontheelectrodewithni fe oxy hydroxideas laser beam used binding agent glue powder electrocatalyst stated 3d printed pla desired structural form 76 process grapheneelectrodewasaneffectiveelectrocatalystagainstoer solid layer formed second layer powder reaction theyconcludedthata10 contributionoffeinthe spread across previous layer preparation coating solution significant kinetic activity oer bonding operation 123 general lot different material initial potential oer reaction comparable areusedintheformofsmallparticlesofceramic wood acrylic iridium ir catalyst fortheni coated3dprintedelectrodes marble metal powder one key advantage another study conducted bui et al 100 technology unbound powder particle act support oer performance alkaline medium produced 3d material printing process therefore support printedelectrodesusingconductivecarbonplafilament material necessary printing process moreover 3d printed electrode electrochemically coated theprinting process finished theremaining powder nickel ni inanalkalineenvironment accordingtotheircv particlescanberecoveredeffectively thus metalprinterswill result theystatedthatoxidationandreductionpeaksoccurred good level five year may game inthepositiveandnegativescanninglimitsforoerandher changer production industry asagraphene basedblackmagicplaapplication iffelsberger 2 3 1 metallic additive manufacturing method et al 106 prepared electrode 3d printing deposited electrochemical application good electrode electrochemically mo surface prepared production method metallic technique generated x electrode coating mo provided excellent much interest electrochemical energy conversion study x electrochemical activity acidic medium 0 5 possible use many production technique surface h another electrochemical energy conversion modification method metallic 3d printed part develop 2 4 application graphene basedconductivepla based3dprinted ment application become popular electrode also studied photoelectrochemical sensor electrochemical application like battery production desired supercapacitor application form circular disk geometry biosensors supercapacitors fuel cell system 3dprintedelectrodesforsupercapacitorapplicationsexhibited etc possible bind powder particle together specific capacitance 98 37 fg 1 also supplied using high power laser beam fuse powder particle promising capacitance performance stable cycling melting point sl reach melting stability 1000 charge discharge cycle 108 utilizing temperature slm combine powder particle 124 conductive material appropriate 3d printing may laser beam coupling system used titanium offer novel electrode electrochemical application steel aluminum bronze nickel precious metal based morphological structural property electrode used alloy 125 127itispossibletousemanyproductiontechniques electrochemical application arranged according andsurfacemodificationmethodsinmetallic3dprintedparts printing parameter composition material pretreat development application become mentparametersofthepolymerfilamentsareimportantinthe popularinelectrochemicalapplicationslikebatteryproduction preparation process 3d printed electrode infill indesiredgeometries biosensors supercapacitors andfuelcell ratio print layer thickness printing orientation system etc sl slm technique electrode prepared using fdm method preferredmetal based3dprintings apartfromthesemethods changed researcher may opportunity ebm method us electron beam instead laser explain whether parameter change electro bindmetal powder one theotherpreferred method chemical property carbon graphene based electrode method seen alternative slm asanimportantissue changingtheshapeandsizeofdifferent technique 128 129 powder bed binder jetting pbbj electrode complex geometry yet method form metal powder using liquid binder sufficiently investigated moreover due constraint method sintering pressing method used producing different geometric shape little known improve mechanical property 23 powder directed 40643 http doi org 10 1021 acsomega 2c05096 acsomega2022 7 40638 40658acs omega http pub ac org journal acsodf review energy deposition pded direct laser metal deposition moreover slm 3d printed part bond strength higher dlmd method themetalpowdercomingtotheactivearea sl 3d printed part general iscalledthemeltingpool itismeltedwithaheatsource commercial slm3d printingprocess uses20 50µmparticle focused point solid object formation 130 131 size metal powder print metal layer 20 100 electrochemical energy conversion system porous electrode µm thickness 137 difficult reduce size show high performance industrial process metalparticlesduetopostpressstructuraldefectsandtechnical larger surface area offer major advantage electrode difficulty minimum feature size reported slm duetotheirhighermasstransfer forexample arenasetal 132 therangeof40 200µm 138asapromisingenergyconversion fabricated highly porous s structure m2multi application ambrosiandpumera139investigatedthehydrogen laser concept laser gmbh 3d printing device using production performance s electrode structure slm method electrochemically coated ni produced slm method stated s acidicbathsolutionusingarectangularchannelflowcell electrodeproducedbytheslmmethodwasconductive butit concludedthatthemasstransportpropertiesofthe3dprinted poor catalytic property hydrogen oxygen ni coated s electrode better typical planar evolution reaction provide higher catalytic activity expanded metal structure another study ibrahim et al 133 corrosion resistance ni pt iro coated s 2 producedsselectrodesusingtheslmtechnique theyaimed electrode surface figure 5 basket shaped electrode toobtainporouselectrodeswithincreasedsurfaceareaforuse production procedure slm method seen electrochemical field purpose tried determine suitable printing parameter using concept laser mlab cusing brand metal printer concluded low laser power high scanning speed porousstructureswouldprintmoreappropriately inaddition high costequipmentandmethodswereusedfortheprocessing metallic material metallic object may produced high precision desired dimension detail 3d printed product metal powder seen great advantage desired geometry thanks method possible obtain electrode figure 5 production step electrode produced slm high surface area result coating produced method reprinted permission ref 139 copyright 2018 productsusingdifferentammethods propertiesofpartssuch john wiley andsons higher strength corrosion resistance conductivity electrocatalytic activity enhanced application seen figure 5 coated basket shaped electrode ability produce unique geometry desired obtained successfully direct electrolysis process may dimension mean wide range effective system may used similar structure another study ambrosi et achieved electrode many application al 140 produced s electrode helical structure advantageous metallic undoubtedly provides slm method coated thin film iro increase 2 revolutionary development electrode used field catalytic activity s electrode figure 6 helical shaped summary great innovation would possible use electrode dimension ranging 1 5 9 cm method field electrochemistry seen 2 3 1 1 selective laser melting method slm method thepowderparticlesarecompletelymeltedduetothe significantly high laser melting process 134 135 figure 4 schematic illustration fundamental working principle slm method seen thisprocessismoresuitabletocreatedensemetalparts technique surface roughness sample higher electrode produced sl technique 136 figure 6 helical s electrode produced slm method reprintedwithpermissionfromref140 copyright2016johnwiley son electrochemical performance iro coated 2 sselectrodewascomparedwiththeglassycarbonelectrode observed iro coated s electrode lower 2 initial potential glassy carbon electrode another study browne et al 141 used ald combination metal 3dprintingtocreateactivemetal basedelectrodes thus aimed produce highly corrosive 3d printed electrode without need coating producing s figure 4 workingprinciple ofthe slm method electrode slm method optimized activity 40644 http doi org 10 1021 acsomega 2c05096 acsomega2022 7 40638 40658acs omega http pub ac org journal acsodf review adjusting tio layer thickness ald method metallic powder slm method 3d printing 2 schematic representation slm ald method process itwaselectrochemicallycoatedwithpttoincreasethe seen figure 7 catalyticactivityoftheelectrodesample accordingtoauthors knowledgethisstudyhasdemonstratedforthefirsttimeahigh surface area printed electrode integrated reactant deliverysystem asanotherapplicationfortheslmtechnique zhao et al 144 fabricated titanium interdigitated electrode usingtheslmmethod designoftheinterdigitatedelectrodes seen figure 9 figure 7 preparation electrode using slm method coating electrode using ald method reprinted permission fromref 141 copyright2019john wileyand son photoelectrochemistry application lee et al 142 investigated fabricating metal based 3d printed photoelectr figure 9 interdigitated electrode prepared slm method ode electrode consisted conical array reprinted withpermission ref144 copyright2014elsevier produced slm method photo electrochemical water separation performance investi gated due high surface area need efficient photo produce geometry slm machine realizer electrochemical water separation prepared conical array slm50 andti 6al 4vmetalpowderwereusedfortheprinting shaped geometry figure 8 production step 3d process geometry coated polypyrene using printed electrode ti powder seen electrodeposition method reached capacitance value comparable electrode produced lithography method obtain corrosion resistant electrode slm method widely studied example kashapov et al 145 prepared electrode using 3d printer realizer slm 50 model cleaning surface metallic product obtained slm technology used ss316 metalpowderwithaparticlesizeof20 40µmtomanufacture figure8 productionstepsofati basedconicalelectrode reprinted electrode another example qin et al 146 conducted withpermissionfromref142 copyright2017johnwileyandsons experiment increase corrosion resistance electrode produced slm method electrode fabricated improve surface area light absorption slm technique using ti cu material active photoelectrochemical water separation conical shape surfaceareaofthepreparedelectrodeswasdeterminedbyacu selected concluded irregularity conical wire epoxy electrochemical property surface structure caused process affected electrode investigated according result electrodeperformance aspolymericapplications metal based determined heat treated sample le likely structure also studied comprehensively undergo pitting corrosion addition stated oer application produce pure hydrogen oxygen wasteofrawmaterialwasgreatlyreducedwhentheelectrodes electrolysisprocesses forexample huangetal 143investigated printed slm method comparison theproductionofelectrodeswithhighcatalyticactivityforthe traditional method yang et al 147 produced current oer reaction slm method addition used collector bipolar plate gasket gas diffusion layer part slm method produce cellular s design high polymer electrolyte membrane pem water electrolysis electrochemical surface area mechanical property using slm method laser powder bed machine first literature slm technique renishaw am250 produced sample seen figure usedtooptimizeporesizeandelectrochemicalsurfaceareaby 10 comparing 3d electrode commercial metal foam figure 10a c show image parallel flow channel structure result study stated 3d pin flow channel pin flow channel respectively electrodeproducedbytheslmtechniquewasveryuseful imagesofambipolarplatesafterpolishingandcleaningcanbe itmightbeusedtoproduceelectrodeswiththeslmmethod seeninfigure10d f andthesurfacesofamplatesappearto rapidly different shape obtain staggered path much smoother better assembling property gasflow gasdiffusionequipmentmaybedesignedtomaximize interdigitated bipolar plate investigated active surface area within predefined volume 110 performing ex situ situ experiment 80 c another slm study benedetti et al 110 designed electrode forinsitutests theyachievedexcellentperformanceat1 716v improve gas distribution active region porous 2 cm2 designing simpler pem water electrolyzer structure design made ti material using ti al v cell reducing number electrolyzer part 6 4 40645 http doi org 10 1021 acsomega 2c05096 acsomega2022 7 40638 40658acs omega http pub ac org journal acsodf review figure 10 designed produced part pem water electrolyzers parallel flow channel b pin flow channel c pinflowchannelwithlgdl amplatewithparallelflowchannel afterprintingandpolishing e amplatewithpinflowchannelafter polishing f integrated plate pin flow channel lgdl polishing reprinted permission ref 147 copyright2018elsevier decreasedthecontactresistance whichwasveryimportantfor pem water electrolyzers electrochemical performance another study pem water electrolyzers ambrosi et al 148 investigatedtheproductionofallcomponentsforapemwater electrolyzer method part prepared figure 11 production step 3d printed pem water electrolyzer component reproduced ref 148 copyright 2018 american usingboththeslmandfdmmethods theypreferredtouse chemical society ssformetalpartsandthefdmmethodwithplafilamentfor part moreover used electrochemical coating process modify electrode surface electrochemicalactivities thesepartscanbeseeninfigure11 increase catalytic activity metallic electrode theanodewascoatedwith ni fedoublehydroxidefilms cathode coated ni mo situ test 2 uncoated coated electrode performed using linear sweep voltammetry lsv technique stated produced part pem electrolyzer cell high electrochemical performance addition yangetal 149producedbipolarplatesusingtheslm technique magic 20a renishaw am250 metal printer theyconcludedthattheammethodmaybecapableofrapid low cost prototype development renewable hydrogen production fuel cell electrolyzer study popular metallic due flexibility produce gas diffusion electrode bipolar plate example scanning electron microscope sem image metallic 3d printed bipolar plate seen figure 12 figure 12 3d printed bipolar plate produced slm method figure 12a b show sem image flow channel sem image cathode bipolar plate polishing respectively polishing polishing semimageoflandbeforepolishing b semimageof surfaceofthebipolarplatehasroughsurface andmeltingpool land polishing c image 3d printed bipolar plate surface flow channel seen figure 13c polishing image 3d printed bipolar plate polishing showsthesurfaceareaofthe3dprintedcathodebipolarplates reprinted withpermission ref149 copyright2017elsevier beforeandafterpolishing respectively thankstothepolishing process surface bipolar plate become smoother impingementsystem ss316lpowdersinthesizeof5 40μm andmost theexcess sspowder removed canbe seen wereusedintheslmmethod duringtheprocess thepowder figure 12 polishing process important slm bed preheated temperature 200 c kept method 3d printing energy conversion device purified argon environment oxygen level dropped equipment another study laleh et al 150 studied 100 ppm fabrication parameter production high relative density ss316l specimen jet chosen preliminary trial produce high density 40646 http doi org 10 1021 acsomega 2c05096 acsomega2022 7 40638 40658acs omega http pub ac org journal acsodf review table 4 electrochemical application electrode prepared slm method powder afterprocess applicationfield ref s tio coating photoelectrochemistry 141 2 s electropolishing oerelectrode 143 titanium cleaning supercapacitor 144 titanium cleaning photoelectrochemistry 142 s mo ni ni fe electrolyzer 148 2 coating s pt ni iro coating electrochemicalcell 139 2 titanium ptcoating gasreactanttransport 110 s iro coating electrochemicalcell 140 2 titanium annealing rotatingplasma 152 electrode s heating plasmaelectrolyte 145 titanium heating corrosiontestcell 146 copper figure 13 working principle sl method reprinted atmosphere 154 building material may selected permission fromref 155 copyright2014elsevier polymer glass ceramic polymer composite illustration 3d printing method sl method material powder layer scanned relatively given figure 13 meanderscanningstrategy byrotating 67 betweenthelayers inthismethod partscanbeproducedwithaparticlesizeof result indicated ss316l specimen produced approximately200μm 156atthesametime theslsmethodis slm higher hardness lower corrosion resistance suitable processing many different material like 3d compared commercially available electrode moreover printing process polymer metal powder ceramic polycar another corrosion resistant electrode study yang et al 151 bonate nylon nylon glass composite hydroxyapa improved corrosion resistance electrode produced tite 157 method also highly preferred production slm method study used al 12si metal ofenergyconversionmaterials forexample alayavallietal 158 powder produce electrode two different geometry produced graphite bipolar plate directly methanol fuel thegeometriesproducedbytheslmmethodwerecompared cell sl method used phenolic resin binder conventional manufacturing technique prepared theydeterminedthattheporesofthetestedpartsunderliquid electrodesforelectrochemicalmeasurementsusingcopperwire pressurewerecompletelyclosedandtherewasnoleakage epoxy examine electrochemical property acidic environment bipolar layer specimen according electrochemical measurement corrosion resistant easily modified geometry weight loss analysis electrode produced slm method therefore bipolar plate produced using graphite non al 12si metal powder showed better corrosion resistance noble orexpensivenoblemetals moreover theircompatibility thantheas castal 12sialloyinnaclaqueoussolution itwas channel design important place pem concluded difference corrosion resistance electrolyzer stated bipolar plate consist al 12si alloy produced different method due 23 48 total cost pem electrolyzer 159 siliconparticlesizeinthemicrostructure itwasstatedthatthe therefore aimed reduce cost material part produced slm method better mechanical consumption new production method 3d property worse corrosion property casted printing example guo et al 160 integrated branching part inaddition theproductionofelectrodesusingtheslm structure tree leaf bipolar plate designing methodwasseenasamongthepromisingmethodsinthefield bipolar plate used murray law define optimum electrochemical application electrode manufactured configuration biological circulation system according slm technique electrochemical energy numerical experimental study reported conversion system listed table 4 bioinspired interdigitated design significantly improved fuel seen table 4 slm electrode generally produced cellperformanceby20 25 comparedtotraditionalflowfield titanium s material reason selection design inanotherenergyapplicationwiththeslstechnique might high corrosion resistance durability dobrzans ki et al 161 prepared electrode use silicon solar alkaline acidic environment several process also cell investigated appropriate mixing ratio using possible apply produced electrode performance different mixture combination used two different improvement like coating surface treatment etc taking silver powder different particle size fabricate intoconsiderationfortheapplicationareasoftheelectrodes electrode according result silver powder could seen slm electrode appeal wide range used preparation contact layer without compared 3d printing method 153 sio due many crack silicon plate high 2 2 3 1 2 selective laser sintering method another temperature fuel cell solid oxide fuel cell sofcs important metallic 3d printing method sl method another promising application sl 3d printed sl method high energy laser beam used electrode 162nielectrodesmaybesinteredonyttria stabilized sintering process laser sinters powder material zirconia ysz material lower contact resistance high fuse together printing bed preheated sufficient performance sofc application optimizing laser scanning temperaturebyfillingitwithinertgastocreateanon oxidative speed 200 6000 mm laser power 20 190 w 40647 http doi org 10 1021 acsomega 2c05096 acsomega2022 7 40638 40658acs omega http pub ac org journal acsodf review figure 14 schematic representation ofthe dlmd pdedmethod table 5 coating metal based 3d printed electrode printingmethod printingmaterial method coatingmaterial applicationfield ref slm s atomiclayerdeposition tio photoelectrochemistry 141 2 slm s electrodeposition mo niandni fedoublehydroxide electrolyzers 148 2 slm s electrodeposition pt ni andiro electrolyzers 139 2 slm s electrodeposition ni flowcell 132 slm titanium electrodeposition pt gasreactanttransport 110 slm s electrodeposition iro electrochemicalsystem 140 2 sl graphite electrodeposition ni dmfcelectrode 158 2 3 1 3 direct laser metal deposition method another method easily produce heterogeneous material important metallic method dlmd method desiredpropertieswithsuccessiveandsimultaneousdeposition dlmd method powder directed energy deposition different material thanks method contribution pded account three main part 4 5 axis robotic literature provided different study arm apowderinjectionfeedstock andafocusedlaserusedasa improving product quality shortening manufacturing heat source 124 although laser commonly used electron time increasing building volume material diversity beam plasma electric arc also used heat apart metal alloy ded method may source 163 164 figure 14 schematic illustration possible direct ceramic processing oxide carbide dlmd method seen based ceramic high temperature boride nitride based dlmd pded method raw powder material ceramic itisalsoforeseenthatcoatingsorsmall sizedspecial injected stock system melted heat cast ceramic structure may prepared using ded source molten material deposited target method electrochemical energy conversion study surface deposited material solidifies bonded 2 3 1 4 coating application metal based 3d printed thesubstratelayer layer 165 thismethodisahighlyflexible electrode electrochemical application necessary 3d printing method manufacturing device improve electrochemical property increase medical field medium large scale repair 166 corrosion resistance electrode obtained metal method changing thickness printed product based3dprintingmethodsbecauseduringtheelectrochemical adjusting power value heat source powder reaction especially oer highly corrosive medium flow rate main advantage 167 example benarji et contact electrode surface example oxidation al 168 investigated corrosion behavior electrode reaction occur anode side pem water electrolyzers producedbythepdedmethod theelectrodeswereprepared cause high overpotentials cell 170 overcome usingss316metallicpowderwithaparticlesizeof45 105µm highly oxidative medium coating process done heat treated sanding observed high catalytic corrosion resistance material electrode produced pded method lower coatingsofthe3dprintedelectrodespreparedbymetal based corrosion rate ss316 sample produced conven powder given table 5 tional method addition stated decrease accordingtotable5 theslmmethodisthemostcommon theferritephaseofthess316electrodewiththeapplicationof methodinthe3dprintingprocess lowrawmaterialcostsand heat treatment temperature caused increase corrosion rate thus mentioned study pded easy application geometry may reason method may change structure ss316 material widespread use s literature electrodeposition thededmethod anotherapplicationwasconductedbymelia method whichisarelativelyeasiermethodcomparedtoother et al 169 investigated effect microstructure method preferred coating process metal machining process ss304l electrode 3d printed ni pt ti selected coating material due ded method used 45 90 µm powder fabricate theirhighercatalyticactivityandcorrosionresistance asgiven electrode stated corrosion resistance intable3 theapplicationfieldof3dprintersandmetal based theelectrodesmightbeincreasedwithahighercoolingrate electrode wide range electrochemical energy oneof themostusedtechniquesfor3dprinting metal ded conversion system 40648 http doi org 10 1021 acsomega 2c05096 acsomega2022 7 40638 40658acs omega http pub ac org journal acsodf review table 6 comparison positive negative aspect material used 3d printing method application material application positiveaspects negativeaspects ref sofcsandsoecs controlofporousstructures limitedoptionofceramicsfor3dprintingprocess automotiveandaerospaceindustry easyprintingofcomplex extremelyhighmeltingpointofceramics anatomicalstructuresforhuman bodyorgans 173 ceramic biomedical reductioninproductiontime dimensionalprecisionerrorsandlowsurface 174 quality providingbettercontroloverthe sinteringorbondingprocessmayberequiredafter microstructureandcomposition the3dprintingofceramicmaterials noneedforanymolding automotivesector easyprintingoflargeparts highcost chemical highaccuracy poormechanicalstrength epoxy basedresin healthandbiomedical tissue spine verygoodsurfacequality fragileparts 175 photoresin hydrogel surgery neurosurgery postprocessingsuchassanding lowpartlife 176 traumatology etc andmillingisnotrequired noneedforanymolding automotiveandaerospacesectors thermalstability brittleness marine chemicalandsolventresistance poorimpactresistance energysector environmentalstability inhomogeneouspolymerarchitecture 177 thermosetpolymers biomedical mechanicalstrength 178 lowcost fastproduction aerospace lowdielectricconstant itisnotwidelyusedin3dprintingbecauseitis electronics lowmoistureabsorption difficulttolinkphotopolymerizablegroupsto 179 cyanateesters ce theirchains satellitecommunications highthermostability 180 insulationsandadhesives excellentwateruptake 2 4 material electrochemical researcher displayed great effort bring higher application whichiswidelyknownasthe3dprinting technologylevel 183 185forexample masciandaroetal 184and technique used highly flexible technology xing et al 186 produced 3d printed ysz electrolyte self applied conventional thermoplastic thermosets support utilization sofcs stated 3d ceramic carbon epoxy cyanate ester well printingmethodisapromisingtechniquetoobtainelectrolyte combination material 171 172 table 6 comparison self support sofc application another study jia et positive negative aspect material used al 187preparedthe3dprintedyszelectrolytesupportsusedin 3d printing method application listed monolithic sofc stack slm method stated thermoplastic thermosets come fore 3d great potential development sla 3d printing process especially accessible printing process ceramic preparation sofc stack common material fdm however material selection 3d printing technology contribute future thermoplastic mostly limited pla ab filament commercialization sofc stack therefore method thermoset polymer epoxy resin polyester melamine urea thatcanpreciselyutilizethiskindofmaterialstoproducefully etc stronger polymer compared thermoplastic functional low cost high efficiency energy conversion theyaremoresuitabletohightemperatureandtoxicchemical storagedevicesareofgreatimportance itisnotedthatthe3d environmentapplications becausetheymaintaintheirsizeand printing process great potential production shape owing strong covalent bond polymer electrochemical energy conversion storage device chain 181 182 ceramic concrete material produced electrode supercapacitors etc compared traditional by3dprintingmethodswithporesandwithoutanycracksvia production method along use environmentally optimizationofparametersandadjustmentofgoodmechanical friendly material moreover chemically active material like property 3dprintedceramicproductshaveoccurredatrend catalyst center energy conversion application totailormaterialswithahighstrength weightratio anditis reason selection suitable active functional simplified formation complex ceramic lattice many material crucial obtain high performance application 52however comparedwithmetals polymer electrochemical reaction carbon based material othermaterials ceramic basedmaterialshaveoneofthemost graphene graphene oxide go carbon black cb carbon critical challenge method due extremely high fiber cf carbon nanotube cnt often used melting temperature increasing interest 3d catalyst support electrode energy conversion printedcomponentsofsofcsandsoecs studiesfocusedon application 188 189 material extraordinary 3d printed high temperature electrochemical device become chanical chemical electrical andopticalproperties therefore populardue totheiradvantageous therefore the3d printing carbon based material combined technology process important place overcome basic attractedsubstantialattentionfromtheresearchcommunityin limitationsandreliabilityissuesofmanufacturingofsofcsby energy storage electrochemical energy conversion enhancing durability specific power per unit volume application like battery electrode supercapacitors mass however use 3d printing process catalyst support 190 191 moreover carbon material sofc manufacturing still development stage different conductive property gained conductive 40649 http doi org 10 1021 acsomega 2c05096 acsomega2022 7 40638 40658acs omega http pub ac org journal acsodf review propertiesindifferentways andthesematerialscanbequickly table 7 different shaped electrode prepared various obtained energy material using different type 3d 3d printing method printingmethods 83 192 193forexample bianetal 194produced 3d porous carbon anode electrode structure using 3d printingmethodtoimprovepowergenerationinmicrobialfuel cell mfc compared 2d flat anode material stated 3d porous carbon anode structure larger surface area good mass transfer excellent biocompatibility increase electrochemical performance commented use 3d printing technology pore size 3d anode electrode adjusted optimizing surface area mass transfer best mfc performance 3d printed porous carbon material widely used supercapacitors battery electrode idrees et al 195 proposed 3d printed porous supercapacitor based use activated carbon derived packaging waste concluded super capacitor made extrusion based 3d printing method capacitance 328 95 mfcm 2 2 5 stated high capacitance value due porous carbon used active material high loading activated carbon material electrode considering circumstance material based 3d printing technology application provide opportunity research 3d printable material electro chemical energy conversion application future 3 differentgeometricshapesintheadditive manufacturing process electrochemical energy conversion application contrary popular belief 3d printing method offer wide opportunity energy material different geometric shape obtained combining product produced 3d printing method possible obtain part electrode bipolar plate 3d printing method energy field production stage product geometry structure interesting different geometric shape common point term production technique application area geometric structure produced using different method sl slm fdm sla diw ijp compared intable7 electrodesproducedusingthedifferent3dprinting method seen seen table 7 different geometry several application many advantage term technique one advantage significant increase surface area geometric shape today geometric structure classical electrode preferredinmanyapplications areinsufficienttodevelopthese system determine geometric shape used 3d printing method electrode named interdigitated framework according structural property spatial dimension 203 example arthur et al stated would notbeanappropriateapproachto3dprintthickelectrodesfor battery store energy 207 geometry design interdigitated structure arranged mutually interlacing located way anode cathode positioned opposite spatial ohmic loss decrease lower distance plane 208 stated three dimensionally inter interdigitated framework electrode compared locking structure minimize ionic path length conventional electrode long et al 210 examined energy electrode thick cell 209 also concluded capacity active surface area property electrode 40650 http doi org 10 1021 acsomega 2c05096 acsomega2022 7 40638 40658acs omega http pub ac org journal acsodf review order compare advantage 3d design interdigitated product also reduce energy consumption required electrodeswith2dparallelplateelectrodes accordingtotheir production process moreover method result theystatedthattheelectrodeswithconventionalplanar accepted one new generation solution battery configuration much lower ohmic resistance production novel electrode field energy storage conventional battery bowen et al 211 used similar energy conversion electrochemical application geometrystructureintheirstudyandtheystatedthatthehigh difficult produce flow channel electrode voltage obtained due structure geometry bipolar plate utilized energy application interdigitated electrode furthermore film structured machiningmethodsduetoboththecostandcomplexityofthe geometry 3d printed thin layer difference geometric structure therefore method become electrode conventional electrode increasingly popular term freedom design material solid structure designed microstructures saving ease generation complex structure wide addition possible add polymer fiber variety material polymer material metal printing 3d film electrode example since ceramic thermosets resin ester may 3d printed interdigitate greater height film structure using different method rapid advance anode cathode always interdigitated pair technology however many study structure determined using larger height applicabilityofothermaterialsinelectrochemicalstudiesusing interdigitate moreporosityisprovidedbyincreasingtheactive method owing still development therefore surface area electrode 203 framework expanding selection material 3d printing electrode examined structurally porous electrochemical device component well research structurelikeasieve thankstothisporousstructure theyare development electrochemical energy conversion applica frequentlyused inareas suchmaterial loading geometric tions still topic explored addition enables designsoftheelectrodeshaveshownunlimitedvariability theuseofawidevarietyofprintablematerials whichwillopen example cheng et al 204 stated electrode subject new opportunity design application area 3d shrinkage structural damage fabrication printing technology 3d printed production complex performed electrode self supporting mesh geometry electrode electrochemical application hemispheresurfacedesigntoavoiddegradation intheanalysis using method lead way electrochemical measurement concluded radial array design transformationindifferentgeometricshapesinthefuture asa spherical surface higher capacity important result geometric shape may formed conventional solid state battery way stated wearable flexible technology compatible 3d printed electrode compatible electronic human body also animal body thanks device anditispossibletousecomplexstructuresbythehelp flexiblebiosensors machinesthatinteractwithhumanlearning ofa3dprinting asaresultofthesestudies theimportanceof communicationmaybeprovidedbyflexiblestructuresareable charge transfer electrochemical system emphasized tobeproducedbyammethod theymaybealsousedinthe stated continuous conductive network development wearable battery system compatible structureisneededforelectrontransferinelectrodes 212thus human body system facilitate design phase technology provides structural integrity improving vehicleswithfuelcells therefore inthefuture theuseofthis geometric structure design increasing surface area technology increase various area including r level electrochemicalenergyconversiondevices thepreparationof industrial application electrode different geometry using 3d printing method contribute decreasing ohmic loss author information improving performance increasing amount corresponding author catalyst loaded electrode thanks increasing mehmet fatih kaya engineering faculty energy system performance improvement created need make engineering department heat engineering division erciyes compare geometric design electrode prepared university 38039kayseri turkey erciyesuniversityh2fc 3d especially designed use electrochemical energy hydrogen energy research group 38039 kayseri turkey storage device supercapacitors battery bataryasanenerjivesan tic ltd ti y■ld■r■mbeyaz■t example determined conical array microstructures mah as■ kveyselbul 38039kayseri turkey orcid org helicalshaped basketshapeorsquareshapestructuresprovide 0000 0002 2444 0583 email kayamehmetfatih higher power stability traditional 2d electrode erciyes edu tr design addition future study expected unique shaped design prepared electrochemical author energy conversion device 3d printing technology bulut hu ner engineering faculty energy system engineering department heat engineering division erciyes 4 conclusion future perspective university 38039kayseri turkey erciyesuniversityh2fc production complex part geometry hydrogen energy research group 38039 kayseri turkey difficult produce traditional manufacturing method murat k■st■ engineering faculty energy system achieved using technology without need engineering department heat engineering division erciyes mold production line emerging technology university 38039kayseri turkey erciyesuniversityh2fc method provides potential benefit electrode hydrogen energy research group 38039 kayseri turkey manufacturing sector recently paved way su leyman uysal engineering faculty energy system development novel design industrial application engineering department heat engineering division erciyes herein showed technology decrease university 38039kayseri turkey erciyesuniversityh2fc waste material used manufacturing stage hydrogen energy research group 38039 kayseri turkey 40651 http doi org 10 1021 acsomega 2c05096 acsomega2022 7 40638 40658acs omega http pub ac org journal acsodf review bataryasanenerjivesan tic ltd ti y■ld■r■mbeyaz■t ebm electron beam melting mah as■ k veysel bul 38039 kayseri turkey fdm fused deposition modeling il ayda nur uzgören engineering faculty energy system go graphene oxide engineering department heat engineering division erciyes hydrogen evolution reaction university 38039kayseri turkey erciyesuniversityh2fc lmd laser metal deposition hydrogen energy research group 38039 kayseri turkey lsv linear sweep voltammetry emre zdog engineering faculty energy system lom laminated object fabrication engineering department heat engineering division erciyes mfc microbial fuel cell university 38039kayseri turkey erciyesuniversityh2fc mjm multi jet modeling hydrogen energy research group 38039 kayseri turkey oer oxygen evolution reaction bataryasanenerjivesan tic ltd ti y■ld■r■mbeyaz■t pa polyamide mah as■ k veysel bul 38039 kayseri turkey pa11 polyamide 11 yakup ogu n su zen engineering faculty department pa12 polyamide 12 mechanical engineering erciyes university 38039 kayseri pbbj powder bed binder jetting turkey erciyesuniversityh2fchydrogenenergyresearch pbih powder bed inkjet head 3d printing group 38039 kayseri turkey pc polycarbonate nesrin demir engineering faculty energy system pded powder directed energy deposition engineering department heat engineering division erciyes pe polyethylene university 38039kayseri turkey erciyesuniversityh2fc pem polymer electrolyte membrane hydrogen energy research group 38039 kayseri turkey pei poly ether imide orcid org 0000 0001 8863 8911 peek polyether ether ketone pet poly ethylene terephthalate complete contact information available petg poly ethylene terephthalate glycol http pub ac org 10 1021 acsomega 2c05096 pla polylactic acid pp plaster based 3d printing note ppy polypropylene author declare competing financial interest pps polyphenylene sulfide ppsu polyphenylsulfone acknowledgment p polystyrene theauthorswouldliketogivethanksforthefinancialsupport pu polyurethane scientific technological research council sem scanning electron microscope turkey tubitak 1001researchprojectsfundingprogram sla stereolithography withprojectnumber120m234 theauthorsalsowouldliketo slm selective laser melting thank scientific research project unit erciyes sl selective laser sintering university funding supporting project soecs solid oxide electrolyzer cell contract number fdk 2020 10548 fyl 2020 10547 sofcs solid oxide fuel cell author b h thanks scientific technological research stl standard triangle language council turkey tubitak scholarship s stainless steel 2211 cpriorityareasph scholarshipprogram grant uv ultraviolet number 1649b032000098 u thanks scientific vp vat polymerization technological research council turkey tubitak scholarship 2210 c national priority area sc scholarship program grant number reference 1649b022006356 authorsb h andm k thankthescientific 1 zhang f zhao p niu maddy j survey key technological research council turkey tubitak technologiesinhydrogenenergystorage int j hydrogenenergy2016 scholarship 2250 graduate scholarship 41 33 14535 14552 performance program b h k also thank turkish 2 solangi k islam saidur r rahim n fayaz h areview higher education institution yok 100 2000 ph onglobalsolarenergypolicy renewableandsustainableenergyreviews scholarship program 2011 15 4 2149 2163 3 wiser r rand j seel j beiter p baker e lantz e list abbreviation gilman p expertelicitationsurveypredicts37 to49 declinesin wind energycostsby 2050 natureenergy 2021 6 5 555 565 ab acrylonitrile styrene butadiene 4 toklu e biomass energy potential utilization turkey ald atomic layer deposition renewable energy 2017 107 235 244 additive manufacturing 5 zakhidov r centralasiancountriesenergysystemandroleof bm black magic 3d renewable energy source applied solar energy 2008 44 3 218 cad computer aided design 223 6 maczulak e renewableenergy sourcesandmethods infobase cb carbon black publishing 2010 ce cyanate ester 7 bechmann f changing future additive manufacturing cf carbon fiber metal powder report2014 69 3 37 40 clip continuous liquid interface production 8 reynders c 3d printer create blueprint future cnt carbon nanotube sustainabledesignandproduction theguardian2014 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process microstructure 29 schmidt j brigo l gandin schwentenwein mechanicalproperties j alloyscompd 2019 804 163 191 colombo p brusatin g multiscale ceramic component 11 raju r duraiselvam petley v verma rajendran r preceramic polymer hybridization vat polymerization based microstructural mechanical characterization ti6al4v refur technology additivemanufacturing 2019 30 100913 bishedpartsobtainedbylasermetaldeposition materialsscienceand 30 appuhamillage g chartrain n meenakshisundaram v engineering a2015 643 64 71 feller k williams c b long e 110th anniversary vat

12 liu z wang wu b cui c guo yan c acritical photopolymerization based additive manufacturing current trend review fused deposition modeling 3d printing technology future direction material design ind eng chem re 2019 manufacturingpolylacticacid part international journalof advanced 58 33 15109 15118 manufacturingtechnology 2019 102 9 2877 2889 31 li j pumera 3dprintingoffunctionalmicrorobots chem 13 popescu zapciu amza c baciu f marinescu r soc rev 2021 50 4 2794 2838 fdmprocessparametersinfluenceoverthemechanicalpropertiesof 32 mallick franke l rösch g lemmer u shape polymerspecimens review polym test 2018 69 157 166 versatile 3d thermoelectric generator additive manufacturing 14 dey yodo n systematic survey fdm process ac energy letters2021 6 1 85 91 parameter optimization influence part characteristic 33 zhang lim w duran f loh x j suwardi journalof manufacturing andmaterialsprocessing2019 3 3 64 additive manufacturing thermoelectrics emerging trend 15 salentijn g oomen p e grajewski verpoorte e outlook ac energy letters2022 7 720 735 fused deposition modeling 3d printing bio analytical device 34 kodama h automatic method fabricating three fabrication procedure material application analytical dimensional plastic model photo hardening polymer review chemistry2017 89 13 7053 7061 scientific instruments1981 52 11 1770 1773 16 vaithilingam j prina e goodridge r hague r j 35 mekonnen b g bright g walker study state edmondson rose f r christie surface chemistry arttechnologyoflaminatedobjectmanufacturing lom cad ti6al4v component fabricated using selective laser melting cam robotics factory future springer 2016 pp 207 biomedicalapplications materialsscienceandengineering c2016 67 216 294 303 36 park j tari j hahn h characterization 17 sterling j torries b shamsaei n thompson laminated object manufacturing lom process rapid prototyping seely w fatigue behaviorandfailuremechanismsofdirectlaser journal 2000 6 36 50 depositedti 6al 4v materialsscienceandengineering a2016 655 37 crump apparatus method creating three 100 112 dimensional object google patent 1992 18 galarraga h lados dehoff r r kirka 38 yang chen z song x zhu b hsiai wu p nandwana p effectsofthemicrostructureandporosityonproperties xiong r shi j chen zhou q shung k k three ti 6al 4v eli alloy fabricated electron beam melting ebm dimensional printing high dielectric capacitor using projection additivemanufacturing 2016 10 47 57 based stereolithographymethod nanoenergy 2016 22 414 421 19 zhu f macdonald n p skommer j wlodkowic 39 huang leu c mazumder j donmez additive biologicalimplicationsoflab chipdevicesfabricatedusingmulti manufacturing current state future potential gap need jetmodellingandstereolithographyprocesses bio memsandmedical recommendation j manuf sci eng 2015 137 1 014001 microdevicesii internationalsocietyforopticsandphotonics 2015 40 forster forster material testing standard vol 9518 p 951808 additive manufacturing polymer material state art 20 kitsakis k moza z iakovakis v mastorakis n kechagias standard applicability nationalinstitute standardsandtechnology j investigation dimensional accuracy multi jet modeling gaithersburg md 2015 http doi org 10 6028 nist ir 8059 part proceeding international conference applied 41 abbott tandon g bradford r koerner h baur j mathematics computational science engineering crete greece process structure property effect ab bond strength fused 2015 21 cotteleer joyce j 3d opportunity additive manufactur filament fabrication additivemanufacturing 2018 19 29 38 42 park j lee j e lee h b park j lee n k son ing path performance innovation growth deloitte review 2014 14 5 19 park h 3d printing bio based polycarbonate potential 22 farzadi waran v solati hashjin rahman z application ecofriendly indoor manufacturing additive manufac asadi osman n effect layer printing delay turing 2020 31 100974 mechanicalpropertiesanddimensionalaccuracyof3dprintedporous 43 matos b rocha v da silva e j moro f h prototype bone tissue engineering ceram int 2015 41 7 bottene c ribeiro c dossantosdias antonio g 8320 8330 amaral c cruz deoliveirabarud h g silvabarud h 23 ziaee crane n b binder jetting review process evaluation commercially available polylactic acid pla filament material method additivemanufacturing 2019 28 781 801 for3dprintingapplications j therm anal calorim 2019 137 2 24 li x liu b pei b chen j zhou peng j zhang x 555 562 jia w xu inkjet bioprinting biomaterials chem rev 2020 44 guo r stuebling e beltran mejia f ulm kleine 120 19 10793 10833 ostmann ehrig f koch 3d printed terahertz rectangular 25 angelopoulos allenby c lim zamorano waveguide polystyrene topas comparison journal engineering inkjet bioprinting process toward translational infrared millimeter terahertzwaves 2019 40 1 1 4 therapy biotechnologyandbioengineering 2020 117 1 272 284 45 houshyar sathish kumar g padhye r shank r 26 zhang wu l guo x kane deng jung g bhattacharyya polyamide nanodiamond filament mater lett lee j h zhang j 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omega http pub ac org journal acsodf review 46 larraza vadillo j calvo correas tejado olza production scale multi jet fusion printing process additive pen rodríguez c arbelaiz eceiza cellulose graphene manufacturing 2018 22 381 387 basedpolyurethanenanocompositesforfdm3dprinting filament 69 redondo e mun oz j pumera green activation using property andprintability polymers2021 13 5 839 reducingagentsofcarbon based3dprintedelectrodes turninggood 47 haleem javaid polyetheretherketone peek andits electrode great carbon 2021 175 413 419 manufacturingofcustomised3dprinteddentistrypartsusingadditive 70 blackmagic3d blackmagic3dconductivegraphenecomposite manufacturing clinical epidemiology global health 2019 7 4 2022 http 3dcompare com material product black magic 3d 654 660 conductive graphene composite 1 75 mm accessed2022 48 jiang liao g xu liu f li w cheng li z xu 71 proto pasta proto pasta composite pla electrically conductive g mechanical property analysis polyetherimide part fabricated filament 2022 http www proto pasta com page conductive pla fused deposition modeling high perform polym 2019 31 1 accessed2022 97 106 72 filament e electrifi conductive pla filament 2022 http 49 hoskins dearn k kukureka mechanical performance www multi3dllc com product electrifi accessed2022 ofpeekproducedbyadditivemanufacturing polym test 2018 70 73 vernardou vasilopoulos k kenanakis g 3d printed 511 519 graphene based electrode high electrochemical performance 50 de leon c chen q palaganas n b palaganas j appl phys mater sci process 2017 123 10 1 7 manapat j advincula r c high performance polymer nano 74 louloudakis vernardou spanakis e katsarakis n composite additive manufacturing application react funct koudoumas e electrochemical property vanadium oxide polym 2016 103 141 155 coating grown apcvd glass substrate surf coat technol 51 serrano borreguero garrido rodríguez j f 2013 230 186 189 carmona theroleofmicrostructureonthemechanicalproperties 75 vernardou louloudakis spanakis e katsarakis n polyurethane foam containing thermoregulating microcapsules koudoumas e electrochemical property vanadium oxide polym test 2017 60 274 282 coating grown hydrothermal synthesis fto substrate new 52 ngo kashani imbalzano g nguyen k hui j chem 2014 38 5 1959 1964 additive manufacturing 3d printing review material 76 ambrosi pumera 3d printing technology method application challenge composite part b engineering 2018 143 172 196 electrochemical application chem soc rev 2016 45 10 2740 53 rabe 3d printing textile new way textile surface 2755 modification 54thman madefiberscongr dornbirn austria 2015 77 lee k ambrosi pumera 3d printed metal 54 tsuji h poly lactic acid synthesis structure property electrode heavy metal detection anodic stripping processing application wiley 2011 voltammetry electroanalysis2017 29 11 2444 2453 55 ghalia dahman biodegradable poly lactic acid 78 kumar k ghosh k alduhaish pumera metal based scaffold synthesis biomedical application journal plated 3d printed electrode electrochemical detection polymerresearch 2017 24 5 74 carbohydrate electrochem commun 2020 120 106827 56 swetham reddy k huggi kumar acritical 79 rohaizad n mayorga martinez c c novotny f webster reviewonof3dprintingmaterialsanddetailsofmaterialsusedin r pumera 3d printedag agclpseudo referenceelectrodes fdm int j sci re sci eng 2017 3 2 353 361 electrochem commun 2019 103 104 108 57 katz plastic commonobjects classicdesigns withacollector 80 ba f kaya f 3dprintedanodeelectrodesformicrobial guide harryn abrams newyork 1984 electrolysis cell fuel 2022 317 123560 58 coon c pretzel b lomax strlic preserving rapid 81 foster c w p zhang ji x rowley neale prototype areview heritage science2016 4 1 1 16 j smith g c kelly p j bank c e 3dprintedgraphenebased 59 olivera muralidhara h b venkatesh k gopalakrishna energystorage device sci rep 2017 7 1 42233 k vivek c plating acrylonitrile butadiene styrene ab 82 manzanarespalenzuela c l novotny f krupick p sofer plastic areview j mater sci 2016 51 8 3657 3674 z k pumera 3d printed graphene polylactic acid electrode 60 ultimaker ultimaker filament 2022 http ultimaker com promisehighsensitivityinelectroanalysis anal chem 2018 90 9 material accessed2022 5753 5757 61 teixeira l c santini c surfaceconditioningofabs 83 zhang j yang b fu f f dong x dai metallization without use chromium bath journal resistivity anisotropy characterization 3d printed materialsprocessingtechnology 2005 170 1 2 37 41 acrylonitrile butadiene styrene copolymer ab carbon black cb 62 karahaliou e k tarantili p stability ab compound composite applied science 2017 7 1 20 subjected repeated cycle extrusion processing polym eng sci 84 kwok w goh k h h tan z tan tjiu w 2009 49 11 2269 2275 w soh j ng z j g chan z hui h k goh k e j 63 dupaix r b boyce c finite strain behavior poly electrically conductive filament 3d printed circuit sensor ethylene terephthalate pet poly ethylene terephthalate applied materialstoday 2017 9 167 175 glycol petg 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4838 85 gnanasekaran k heijmans vanbennekom woldhuis 64 maddah h polypropyleneasapromisingplastic areview h wijnia de g friedrich h 3d printing cnt j polym sci 2016 6 1 1 11 graphene based conductive polymer nanocomposites fused 65 dudek p fdm 3d printing technology manufacturing deposition modeling applied materialstoday 2017 9 21 28 compositeelements archivesofmetallurgyandmaterials2013 58 4 1415 1418 86 rymansaib z iravani p emslie e medvidovic kosanovic sak bosnar verdejo r marken f polystyrene 3d 66 mohamed masood h bhowmik j l optimization offuseddepositionmodelingprocessparameters areviewofcurrent printed electrochemical device embedded carbon nanofiber researchandfutureprospects advancesinmanufacturing2015 3 1 graphite polystyrenecompositeconductor electroanalysis2016 28 42 53 7 1517 1523 67 sood k ohdar r k mahapatra parametricappraisal 87 spinelli g kotsilkova r ivanov e petrova doycheva ofmechanicalpropertyoffuseddepositionmodellingprocessedparts menseidov georgiev v di maio 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