Processing of Nanocomposites for Biomedical Applications

V. Kavimani and P.M. Gopal
Department of Mechanical Engineering,
Karpagam Academy of Higher Education, Coimbatore, Tamil Nadu, India
manikavi03@gmail.com; gopal33mech@gmail.com

Kapil Gupta
Mechanical and Industrial Engineering Technology
University of Johannesburg
Johannesburg-RSA
kgupta@uj.ac.za

Abstract

This paper introduces the classification of nanocomposites materials and processing methods involved in developing nanocomposites for biomedical application. Nanocomposite finds application in various fields of industrial and academic sector due to its fascinating properties. However the processing of nanocomposites materials have not been well exposed due to properties such as high surface area and agglomeration tendency etc. This paper provides a deep insight on various methods available for developing nanocomposite materials.

Keywords
Nanocomposite, bio-medical; solid state processing, liquid state processing

1. Introduction

Generally, composites that exhibit nanometres scale in any one of their dimensional phases are termed as nanocomposites (Kavimani et al. 2017). These are emerging materials for bio medical applications and also projected as appropriate substitutions to overcome the perimeters of micro composite. Nanocomposite has wider application in the field of biomedical that includes drug delivery, tissue engineering, medical implants etc. (Figure 1). These nanocomposites have come into sight as appropriate substitute to surmount confines of monolithic and micro composites, while posing preparation challenges connected with control composition of element and stoichiometry in nano cluster phase. Nanocomposites have concerned responsiveness in both research and industrial sector due to their effectiveness in developing multifunctional materials with superior properties. These nanocomposites are the emerging materials in the field of bio medical engineering owing to their unique properties that includes better healing over fractured bone surfaces, light weight and high strength to weight ratio. Nanocomposites generally consist of an organic matrix phase in which inorganic nanomaterials are uniformly dispersed which is also termed as reinforcement phase. Herein the reinforcement may be nanotubes, nanorod, nanoclay, and nanowires etc. Similar to micro-composites, these nanocomposite materials can be classified into three major classification based on nature of matrix phase material are (Kavimani et al. 2017):Ceramic based nano composite; Metal based nano-composite; Polymer based nano composite

1.1 Ceramic based nanocomposites

As the name implies Ceramic Based Nano Composite (CBNC) constitutes of ceramic material as the matrix phase that is surrounded by nanomaterials to enhance the functional behavior of ceramic matrix. These CBNC showcase important class of application in field of biomedical. This fact was owed to nanocomposite's unique properties such as high wear resistance, biocompatibility, and chemical inertness with better mechanical strength(Javadhesari et al 2019). These CBNCs are mainly used as coating material over the surface of metal substrate with thickness of coating in range of Nano metric scales (thin film) for biomedical applications.

In past decade's bio-ceramic material namely Hydroxyapatite (HA) which is similar to structure and chemical composition of human bones used for biomedical based application particular in the field of orthopedic implants. These bio ceramics exhibits better osseo integration rate, chemical stability and biocompatibility. HA materials are consider as candidate material for developing thin film coating for bio medical implants whatsoever these material exhibits high brittleness due to the ceramic nature and inferior mechanical properties viz. hardness, toughness etc. that limits the usage of HA in various load bearing bio implants applications. To avoid these kinds of issues, various nanomaterials such as titanium di oxide nanoparticles in the form of rods, tubes, single walled carbon nanotubes, and alumina are used as the reinforcement material to improve the mechanical strength of HA material. However processing of bio-ceramic nanocomposites was quite difficult due to the agglomeration tendency of nanomaterial. This paper deals with processing of various ceramic matrix composites.

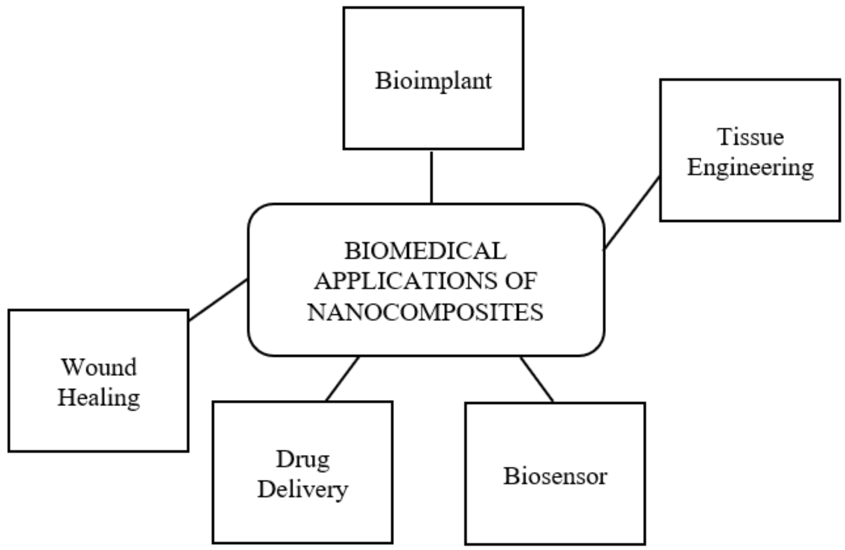

Figure 1 Various applications of nanocomposite in biomedical field.

1.2 Metal based nanocomposites

Metal Based Nano Composites (MBNC) are the combinational materials that consist of metals or alloy in matrix phase that are incorporated with nanomaterial in reinforcement phase (Razavi et al 2010). MBNC are considered as favorable materials for developing Bio-medical implants owing to their acceptable mechanical properties. Based on structure of nanomaterial (reinforcements) MBNC are classified as continuous and discontinuous nanomaterial reinforced nanocomposites. Herein the nanocomposite that consists of tube, rod shaped nanomaterial in reinforcement phase are called as continuous reinforced nanocomposites. Among the available continuous reinforced nanocomposites, carbon nanotube reinforced metal based nanocomposites are consider as the evolving advance material for medical implant based applications due to their better tensile strength.

In recent days, MBNC have better concerned towards, essential research in the field of bio medical implants. In this Magnesium (Mg) based metal and alloys has better biocompatibility and mechanical strength compare to human bone(Xiong et al. 2016). Consequently, these materials are widely used for developing orthopedic based implants instead of conventional metallic materials. Conversely, these metals have fast degradation tendency and lower bioactivity this fact act as the major constrain for usage of Mg in the area of bio-medical implants. Herein Mg based Nano composites are reported with nanotitanium di oxide, silicon carbide and nano HA to improve the toughness and corrosion resistance. In some research Titanium based nanocomposites are developed to improve the stress bearing strength and biocompatibility nature of titanium for medial implant applications in addition to endorsing Osseo integration thus promotes them as the candidate material for orthopedic and dental based applications(Wu et al. 2019; Fellah et al. 2019).

1.3 Polymer based nanocomposites

The Polymer Based Nano Composites (PBNC) consist of polymer based material as the base matrix and nano-sized materials as the filler or reinforcement phase. PBNC has significant properties viz. lightweightness and high ductility, which made them as candidate material for developing medical implants. PBNC has better modulus to transfer load while compare to human bones this facts promotes the usage of these materials in orthopedic based application. Further selection of material for implant application has certain requirement viz. chemical stability, non-toxicity etc. Hence the chosen PBNC must satisfies some basic and functional criteria viz. biodegradability, biocompatibility better mechanical strength etc. for wider range of application. For example, poly vinyl alcohol is a polymer material with better biocompatibility and flexibility that has been used in biomedical application conversely these polymers exhibits lower mechanical properties that made them as the inadequate material for orthopedic surgery (Makvandi et al. 2019; Solovev et al. 2019). Some researchers used nanotitanium di oxide, nano HA, boron nitride nanoparticles as the filler material to improve the bioactivity, thermo mechanical behavior polymer materials and attained excellent results in PBNC (Harito et al. 2019). This made the PBNC as the candidate material for biomedical and bone tissue engineering application.

2. Solid state processing of nanocomposites

Under the solid state process, matrix materials are used in solid state without melting them unlike as in liquid state process. The foremost advantage of this process is that a geometrically accurate product can very well be achieved and no further secondary process is needed. Solid state process is well known for fabrication of nanoparticles reinforced composite with homogeneous mixing of reinforcement(Verma et al. 2019).

2.1 Additive manufacturing

Titanium based nano composites are used for developing biomedical implants, these composites are traditionally fabricated by adopting conventional approaches viz powder metallurgy, and stir casting etc (Ebrahimi et al. 2019; Niespodziana 2019). In recent years, usage of additive manufacturing (AM) technique archives special attention owing to its ability to form net shape product with minimal production time. Herein nanocomposites are developed by various AM processes such as direct energy deposition powder bed fusion, laser engineered net shaping, Selective Laser Melting(SLM), and wire arc additive manufacturing etc. (Attar et al. 2020). Conversely, these processes diverge from various machine parameters that include material feeding system and power source configuration system. However these machining parameters are controlled by operational parameters such as melting and solidification etc. which all together influence the properties of the developed components.

Titanium based nano composites such as TiC/A1Si10Mg, IN718/TiC are fabricated using selective laser melting method. Herein base material and reinforcements are used in powder form, to attain homogenous dispersion of reinforcements and matrix material. Calculated weight percentages of reinforcements are mixed with matrix material by ball milling approach(Gu et al. 2014). This uniform dispersion of materials leads to promising flow ability of nanocomposite powder system. The SLM system, consisted of ytterbium based fiber laser with a power of ~200 W and a spot size of 70 μm assisted by an automatic powder spreading system with argon gas environment coupled with process control system. SLM system entails sealed building platform under argon environment with aluminum based substrate to build the nanocomposite materials. Subsequently, the Nano composite powder was deposited over aluminum substrate through the layer by layer mechanism, with required powder layer thickness. The CAD data are utilized to control the scanning of laser beam over power surface of bed to form required dimensional profile.

Cobalt-chromium-molybdenum (CoCrMo) alloys are extensively employed in several load-bearing implants viz hip, spinal and knee applications owing to their outstanding wear resistance. Conversely, these alloys exhibit poor biocompatibility during vivo corrosion conditions, which could be improved by adding suitable reinforcement particles. In some studies, calcium phosphate has been used as reinforcement to improve the basic and functional behavior of CoCrMo alloys (Li et al. 2020). These nanocomposites could be fabricated by laser engineered net shaping approach. Primarily, CoCrMo alloy powder and calcium phosphate nano powder was heat treated. The feed stock powder was prepared with different combination of reinforcements and then processed with laser engineered net shaping approach. In this, laser power source of 400 W and scan speed of 45–60 cm/min were used to depositing the CoCrMo-CaP composites along with a powder feed rate of 60 g/min. The laser surface melting experiments were conducted in an argon environment having oxygen content under 10 ppm(Bandyopadhyay et al. 2019).

Polymers such as poly latic acid, poly-ε-caprolactone, poly hydroxyl butyrate etc. are used for biomedical application which has better biocompatibility. Polymer based nanocomposites has better thermo mechanical properties by adding various nanomaterials as the reinforcement medium such as CNT, Nano clay, graphene etc(Nadernezhad et al. 2019). Polymer based nanocomposites are fabricated using additive manufacturing process in this polymers are taken in powder form and vacuum dried before mixing with nanomaterials (reinforcements). The composite are extruded 450 rpm screw rotation speed with die temperature up to 191 ºC. The pellets formed nanocomposites were used to form filaments by the help of screw extrusion method. Filaments were air cooled after extrusion, while the required diameter by adjusting the winder speeds. These developed filaments are used to fabricate the medical components based on CAD model with assists different additive manufacturing route such fused deposition modeling.

Bio ceramic such as HA have biocompatibility but poor mechanical strength(Xie et al. 2019). Graphene based nanomaterial consist of allotropes of carbon with better chemical stability and superior mechanical strength. Graphene based nanomaterials can enable proliferation and better bonding over of bone cells. Usage of graphene as the reinforcement will defiantly improve strength and elasticity of HA based ceramics. Conversely development of graphene reinforced HA nanocomposites was quite difficulty due to its complex synthesis processes. In addition, there is no established method for developing porous 3D structures, which is essential for bone implantation based application. However these complex structures can be developed with the assistants of AM methods. Initially HA nanocomposite with different weight percentage of graphene was synthesis by wet mixing approach. To formulate the raw material for AM, a dry binder like maltodextrine must be premixed with the nanocomposite powder. Then the whole dispersed powder were dried using hotplate at 90°C. Among the available AM process, the powder-bed method was considered as the simpler and low cost operation method(Azhari, Toyserkani, and Villain 2015). Herein to develop porous structured graphene/HA nanocomposite, initially 3D model was designed using CAD software. Then the developed CAD model was saved in stereolithogaphy (STL) format it was followed by slicing of the developed CAD model. It is followed by feeding the developed sliced model into 3D printer. Figure 2 depicts the development of graphene/HA nanocomposite using AM approach.

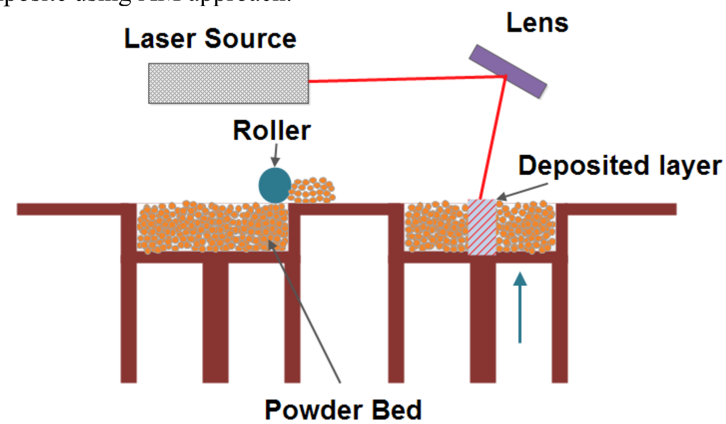

Figure2 Schematic representation of powder-bed additive manufacturing

The powder bed system consist of two powder beds with position adjustments in Z direction with the assistants of piston (placed below the bed) (Azhari, Toyserkani, and Villain 2015). The nanocomposite powders are placed over the feeding bed. Initially a thin layer of composite powders are spread over the building bed. Next, the section moves forward to inject the binder over building bed based on CAD design. The feeding chamber piston push the building bed upward to limited layer thickness after the injection of liquid binder. Next the compartment moves toward backward direction to spread the powder to next layer with the help of rotating roller. Consequently, spread layer of composite powders are prepared to inject the binder for next layer. The same procedure was repeated to attain a porous structure, and then achieved sample was dried to eliminate the binders (Yao et al. 2017).

2.2 Powder metallurgy

Powder metallurgy process involves three major steps (i) mechanical alloying, (ii) compaction and (iii) sintering (Singh et al. 2020).

Initially, calculated weight or volume percentage of reinforcement particles and base matrix materials are taken in the form of powder. The obtained composite mixers are blended by the assistance of planetary ball milling. During powder blending process, regents like stearic acid are added in to the composite powder to attain homogenous mixing. During mechanical alloying, the composite materials are rotated in a cylindrical steal chamber containing spherical diameter ball made up of hard ceramic materials such as TiC or WC. Herein the ceramic balls are selected based on hardness of base matric material. The powder blending process is controlled by two main process parameter namely powder to ball ratio and rotation speed(Kavimani et al. 2020). For reducing the size of particles from macro scale to micro scale, ball having bigger diameter are employed with lower rotational speed. Likewise, maximum chamber speed and smaller diameter balls are used for scale down the micro size particle to nanoscale. For scale downing to nano size, the composite powders are blended with organic solvents in order to avoid the chance of agglomeration. Further the composite mixtures are dried for every 30 min and then allowed to ball mill.

The archived composite powder are processed to second stage called as compaction (Kavimani et al. 2019). In this stage, mechanically alloyed powders are consolidated in a cylindrical die of required dimension and pressed with calculated pressure by the assistants of hydraulic press to attain green compact. The inners sides of dies are coated with some solid lubricants like graphite for easy removal of the compacted materials. In this stage, die design and applied pressure or load play a key role in governing the quality and strength of the composite materials. Since, improper selection of applied load results in increasing range of porosity and material's defects. Generally cylindrical shaped dies are adopted for compaction process since the usage of sharp-edged die results in formation scratches and make some difficulties during loading and unloading in compaction process. Based on available literature survey in die design, aspect ratio must be less than 1 to achieve compacted material with minimal level of porosity. The third stage of powder metallurgy method is sintering. The developed compacted specimen or the green compact must be sintered within 72 hours of compaction process in order to avoid the formation of blowholes that reduces the quality of developed composite material. Herein the green compact are sintered by the assistance of muffle furnace. The sintering temperature of green compact are generally calculated based on the melting point of base matrix material. The sintering temperature is three forth of melting point of base material. And it is to be maintained for up to 4 hrs to attain composite with lower range of porosity. For developing Mg based nanocomposite the obtained green compact are sintered under inert gas atmosphere such as argon to avoid the chance of oxidation since Mg based materials have tendency to catch fire in normal environmental condition. In some cases charcoal based material are used for sintering Mg based composite, usage of charcoal during sintering results in formation carbon di oxide gas that avoid the oxidation of Mg based materials(Kavimani et al. 2017).

Titanium based alloys are extensively used in developing biomedical implants that includes dental, prostheses etc. owing to its excellent mechanical strength and biocompatibility conversely these material displays inferior wear resistant that act as the major barrier for its application. Silicon carbide based Ti-Cu intermetallic composite can be produced with powder metallurgy route which is difficult to develop in casting based methods. Initial stage of powder metallurgy begins with ball milling process in this cold welding, collision of metal powders, plastic deformation and fracture of the composite powders occur repeatedly; This occurrence produces dislocations composite powders. The milling process was carried out with the powder to ball weight ratio 1:10 under argon protection at 300 rpm for 30 h. The stainless steel balls with different diameters could be used for attaining proper dispersion of composites. Stearic acid based controlling agents can be used to speed up the milling process. The ball milled powders were compressed under cylindrical steel molds under the pressure of 1 GPa and then sintered at 900 °C for 1 h to attain Silicon carbide based Ti-Cu (Javadhesari et al. 2019).

2.3 Spark plasma assisted powder metallurgy sintering

Biocompatible composite materials such as Mg–Zn–Mn–Si–HA composites can be fabricated by Spark Plasma Sintering assisted solid state processing. Herein commercially pure metal powder viz as Mg, Mn, Zn, Si, and HA are ball milled with calculate weight percentage of reinforcement particles using planetary ball mill with SS balls with 5 mm diameter for the purpose of mechanical alloying (Prakash et al. 2018; Wang et al. 2012). Generally, the powder to ball ratio is maintained as 1: 10 with speed of 300 rpm for 12 h. During mechanical alloying, reagents like Stearic acid are added to avoid the chance of particles agglomeration that forms as results of cold welding. The attained composite powder was then preheated at argon atmosphere in order to eliminate the wetness of mechanically alloyed powder. Formerly the composite mixers are sintered by Spark Plasma Sintering process. The sintering process is carried out at heat flow rate of 50ºC / min under vacuum environment with varying applied pressure and temperature. The process is represented in Figure 3.

2.4 Dual stage sintering assisted powder metallurgy

For bone tissue engineering application HA- Titanium di oxide based composite materials are used due to its better biocompatibility (Marinescu et al. 2017). Powder metallurgy based approaches are used for developing these types of bio materials. For processing of ceramic based materials, sintering process acts as the key step for composite strength. Since improper section of sintering temperature results in dehydroxylation, coarse grain formation and decomposition of HA based ceramic materials. To avoid these defects dual stage sintering approaches are used. Similar to tradition solid state processing, the composite powder are first cold welded using ball mill. The composite powders are consolidated and cold compacted at pressure of 150 MPa to obtain green compacted pellets. In dual stage sintering approach, the samples are initially sintered at 900º C for 1 to 5 min to avoid dehydroxylation and to attain the bulk density of developed composite. The second stage was followed by rapid cooling from 900º C to 800º C then the temperature was maintained (800 ºC) for 5 and 10 hrs to attained densified and homogenous nanostructure with high stability to avoid the chance of decomposition.

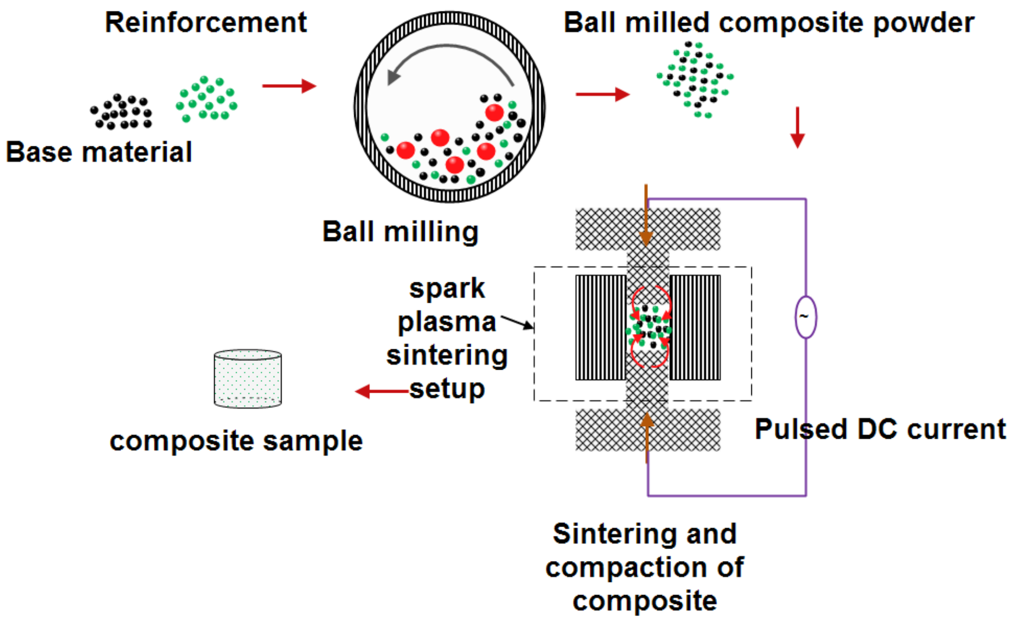

Figure 3 Schematic representation of spark plasma assisted sintering

2.5 Equal channel angular extrusion

Magnesium and its alloys exhibit comparable to mechanical strength of our human bones. These biocompatible materials fabricated by conventional material process techniques such as powder metallurgy and stir casting etc. undergo agglomeration and unreliable performances. In order to extent the wide spread application of Mg based HA composite extensive research has been needed in processing phase. Severe plastic deformation process viz. Accumulative roll bonding, equal channel angular extrusion, and high shear solidification etc. are considered as the one of the processing method to attain fine grained nanocomposites(Agnew et al. 2005). In this shear melt based treatment, rotar stator mechanism help in decreasing the agglomeration tendency and initiates the uniform dispersion of composite materials. In some studies, combined severe plastic deformation i.e equal channel angular extrusion, high shear solidification was used to attained nanocomposite with better functional properties. Herein the base material (Mg-Zn-Zr) was developed by melting pure Mg ingot under protective environment then the calculated amount of alloying element were added to molten Mg up to 1 hr to develop base matrix material. Initially, the base alloy was melted completely and preheated nano HA particles are charged into the matrix material by the assistants of drill-driven propeller. The molten composite materials were acclimatized by means of shearing with the assistants of rotor-stator mechanism with the speed upto 10,000 rpm for about 20 min. During mixing process, high speed rotation help in initiating high shear rate over the composite melt. Then the melt was poured in a steel mold with planned dimension. After composite development, the casted composite materials are seized into square billet for Equal channel angular extrusion process(Y. Huang et al. 2018; Valiev et al. 2006) . This method consists of two equal channels that are intersected at preseted angle (2φ). Initially the developed composite square billet was pressed through the first channel and pulled out from second channel that initiates the occurrences of sever plastic deformation by means of shear mechanism. This helps in attaining high grain refined composite material,

In some studies, cyclic extrusion and compression combined equal channel angular extrusion based Forward extrusion processes(C-ECAP-FE) was adopted to developed high strength Mg-HA composite for bio- medical applications(Y. Huang et al. 2018; Zhang et al. 2008). In this, high purity Mg and HA nano particles are preheated upto 50 °C. The main advantage of the combined process was to consolidating the composite powders without the assistance of external backpressure. Initially, the C-ECAP-FE die was preheated up to 400 °C, the composite powders are imposed in to the die then processed at constant ram speed of 0.2 mm/min.

2.6 Microwave assisted powder metallurgy

HA based Mg composites are usually fabricated by solid state processing such as powder metallurgy process where sintering of composite materials is carried out in electrical furnace that results in high time and energy consuming process. In order to avoid these fact microwaves assisted heating was used to ensure the uniform heating and low energy consumption. Initially the Mg and HA Nano powder was ball milled up to 4 h. The attained composite mixers are cold compacted in cylindrical die. The attained green compact was sintered under microwave assisted furnace for 500 ºC for 10 min under inert gas atmosphere to attained Mg –HA composite (Xiong et al. 2016; Radha et al. 2015).

2.7 Friction stir processing

Friction Stir Processing (FSP), is an effective sever plastic deformation method that helps in attain better surface properties and also alter the microstructure of the materials (Radha et al. 2015). These methods have several advantages such as uniform dispersion of reinforcement's particles, and modification over texture properties etc. Titanium based materials find application in dental and orthopedic implants whatsoever these material have poor wear resistance that limits the wider range of its application. In some studies, SiC based nanoceramic materials used as reinforcement to improve the wear resistance of Ti based matrix material.

For developing SiC reinforced Ti composite, initially the surface of the Ti plate is mirror polished and then cleaned using acetone in order to remove impurities (Zhu et al. 2016). Holes are made over the surface of polished Ti plates surface with 1 and 2 mm diameter. Then the Nano SiC particles are loaded in the holes a constant speed of 50 mm/min at a rotation rate of tungsten steel tool was adapted to 500 rpm. The FSP was carried out in inert gas atmosphere to avoid the oxidation owe to high temperature near FSP zones. The probe was 10mm in diameter with concave shoulder, pin height was 2-mm slanted by 2.5°. The probe was inserted into the work piece for microstructural modification to cover the FSP region. Multiple-pass FSP with 100% cumulative overlap after three passes was implemented for further grain refinement

2.8 Accumulative Roll Bonding

This process is based on principle of severe plastic deformations enforced by revolving rolls on arranged metallic pieces to attain material with fine grain refinement(Lv et. al. 2017; Bhardwaj et al. 2019; K. M. M. Rahman et al. 2019). Metal matrix nanocomposites are fabricated by this technique such as Al/CNT, Mg/CNT etc. Initially the base matrix metal samples are cut into required dimension. Then the matrix plates are wire bushed in order remove the impurities and oxide layer that formed over the surface of matrix materials. After that calculated weight or volume percentage of Nano reinforcement particles are sprayed over the matrix metal surface. After this process the metal sheets are stacked into two sheets on top. Then the thicknesses of stacked composite sheets are reduced to 50 % thickness by the assistance of roll bonding. After that roll bonded samples are divided in to piece and the same process can be repeated for several pass based on our requirement to attain composite material with fine grain refinements (Figure 4).

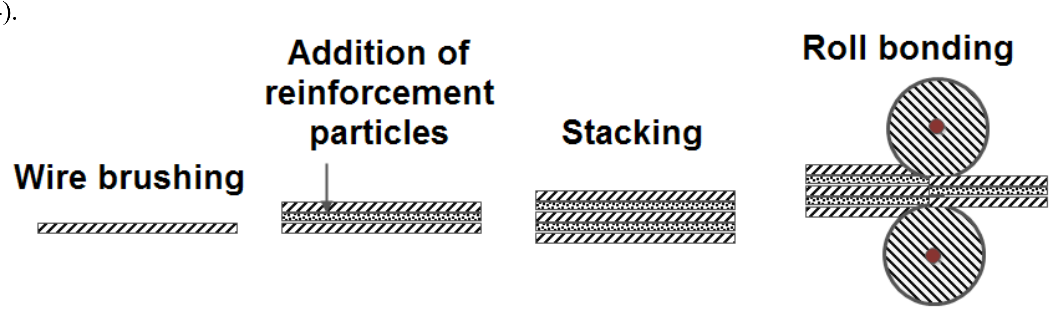

Figure 4 Schematic representation of accumulative roll bonding process

3. Liquid state processing of nanocomposites

3.1 Stir-Casting

Stir-casting was consider as the economical, and simple method developing metal matrix nanocomposites wherein the hard reinforcement particles viz SiC,TiC etc. are integrated into molten base matrix metal (Ramezanzade et al. 2019). A graphite coated impeller or stirrer was inserted into molten base metal to a calculated speed to form vortex that helps in homogenous dispersion of reinforcements particles in molten base matrix material. This process has been comprehensively used to integrate hard ceramic particles, carbon based Nano materials such as graphene and certain metal oxides. The foremost challenges of stir casting method is the agglomeration of nanomaterials due to its high surface area, these nanomaterials showcase poor wettability that act as the main barrier in mixing up of matrix and reinforcement particles. Third challenge is the porosity formation owing the effect of stirrer that trap the air into the composite mixture during mechanical stirring process.

3.2 Disintegrated Melt Deposition

This method was a modification of stir casting process mainly used for development of Mg based nanocomposite used in biomedical application(Gupta et al. 2015). In this technique, composite materials are converted to slurry form based on the principles of stir casting. Then the formed slurry materials are passed through a nozzle under inert gas atmosphere at a superheated temperature. At the end, the slurry is deposited in a mold based on the required dimension either cylinder or cube. The attained composite materials is the end product of Disintegrated Melt Deposition which can be further undertake into secondary process such as ECAP, and hot extrusion etc.

4. In-situ processing of nanocomposite

4.1 Melt intercalation

This method has been used for synthesizing ceramic particle based polymer nanocomposites(Z. Huang et al. 2020). This technique has several advantages while compared with intercalative polymerization and solution intercalation. Herein matrix materials viz polymers are heated at specified temperature to attained molten matrix material and then reinforcements are mixed with nanomaterials. Further these polymer composites are further processed with various secondary process such as extrusion etc.

4.2 Dispersion based composite processing

Polyethylene based polymers are widely used polymeric material in biomedical applications. However these polymer exhibits poor wear resistance that limits there application in orthopedic and implants area(Taromsari et al. 2019). Some biocompatible ceramic material such as HA and high strength carbon materials such as graphene Nano plates are used to improve the essential behavior of composite for biomedical application. In some studies, facile synthesis routes such as dispersion methodology was widely used to developed polymer composite with required properties. These dispersion methodologies consist of ultrasonic cation for solvent based mixing of reinforcement material further assisted by hot compression process. As said before, the base material and reinforcement particle are mixed using ultrasonic assisted stirring process. The attained composite mixture was the stirred under magnetic stirrer assisted hot plate system for up to 15 min to remove the organic impurities. The attained samples are dried in hot air oven for up to 24 hrs to dried out ethanol and the dried composite mixture was hot pressed to attain HA-GNP-Polyethylene composite

4.3 Liquid infiltration

In this process, initially the mixing of reinforcement particles with base matrix metal material takes place and followed by thermal treatment of base material and reinforcement particles by means of liquid infiltration methodology(Roger et al. 2019). Then the developed composite materials are thermal treated below the melting point of based matrix material in order to remove the internal porosity of the composite material.

4.4 Spray pyrolysis

This method consist of five steps, initially the precursors of matrix and reinforcement materials are dissolved in appropriate organic or inorganic solvent to attain composite material in liquid form, next the attained liquid source of composite materials are converted in fog or mist form using ultrasonic atomizer (Saravanakkumar et al. 2018). Then the attained composite mists are preheated under hot air oven. Then the composite materials are obtained in oxides form by decomposition of preheated sample with the help of vaporization technique. The synthesis composite metal oxides are converted to metallic materials by means of reduction of metal oxide.

4.5 Sol-Gel Process

Polymer based nanocomposites are widely synthesized by in sol-gel process(I. A. Rahman et al. 2012). It consists of two reactions, one is hydrolysis and other one is poly-condensation reaction of inorganic precursor dissolved in an organic medium, These reaction lead to the development polymer based nanocomposite and the attained mixers are dry under hot environment to dry the composite mixture and then nanocomposite was attain by heat treatment of consolidated powder.

Table 1 presents a comparative evaluation in terms of advantages and limitations of various nanocomposite fabrication processes.

Table 1. Advantages and limitations of nanocomposite fabrication processes

Method	Advantages	Limitations
Additive manufacturing	• Fabrication of complex component shapes • Combine manufacturing and assembly into a single process	• Material strength depends on characteristics of powder used • Not efficient in producing a high volume of parts.
Powder metallurgy	• Manufacturing near-net-shaped products • Produced component will have controlled porosity	• Difficult in choosing optimal process parameters viz. sintering, pressing • Powder materials are costly
Spark plasma assisted powder metallurgy sintering	• Efficient energy saving process	• Only symmetrical parts can be developed
Microwave assisted powder metallurgy	• Selective heating process and rapid heating	• Expensive process
Friction stir processing	• Fine grain refinement in microstructure	• Only surface composite can be develop • Developed material will have poor resistance to inter granular corrosion
Accumulative roll bonding	• Bulky sheet materials with improved strength can be developed	• Not advisable for developing complex parts
Stir-Casting	• High production rate and flexible low cost	• Attaining uniform dispersion and lower porosity is quite difficult due to agglomeration tendency of nanomaterial
Melt intercalation	• Suitable for industrial based polymer process	• Suitable only for developing polymer composite
Liquid infiltration	• Rapid solidification • Material with different stiffness can be develop	• High temperature process
Spray pyrolysis	• Ultra-fine multicomponent system can be develop	• High cost
Sol-Gel Process	• High purity products • Simple and low temperature process • High homogeneity material can be synthesized	• Process reproducibility was poor • Cost of precursors was high • High shrinkage during drying process • Moisture sensitivity

5. Conclusion

This paper has provided the detailed reviews on various processing techniques for nanocomposite material. Herein the composite materials are classified based on matrix materials either ceramic, metal and polymer. Fabrication techniques involved in the development these nanocomposite has been described by solid, liquid and in-situ process. That helps the researchers to understand the techniques adopted for processing nanocomposite for biomedical application. The important future research avenues are selection of suitable processing method for specific combinational of reinforcement and matrix, it is essential to find out a better way to improvise the interaction between reinforcement and base matrix material and incorporation of nanomaterial in matrix with uniform dispersion, optimal parameter for composite fabrication such as reinforcement weight, process parameter, development of lower cost processing method, process analysis using modelling and simulation etc.

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Biographies

V.Kavimani is an Assistant Professor in Department of mechanical Engineering at Karpagam Academy of Higher Education, Coimbatore, Tamil Nadu, India. He received his Ph.D. under the Faculty of Mechanical Engineering on March 2018 from Anna University Chennai. His area of research includes Lightweight materials, Bio composite; Surface coating, Graphene based composite development and Nanomaterial synthesis. He had published around 28 international journals in his research area. He is the reviewer for many reputed journals that includes Material Letters, Alloys and Compounds, Building Engineering, Composite structures, Progress in organic coating, Magnesium and its alloys, Tribology Letters, Silicon etc.

P.M. Gopal is an Assistant Professor in Department of mechanical Engineering at Karpagam Academy of Higher Education, Coimbatore, Tamil Nadu, India. He received his Ph.D. under the Faculty of Mechanical Engineering on December 2017 from Anna University Chennai. His area of research includes Additive Manufacturing, Composite Materials, Material Characterization, Waste Management and High Entropy Alloys. He had published around 22 international journals and 2 book chapters in his research area. He is the reviewer many reputed journals that includes Measurement, Journal of Industrial textile, Silicon etc.

Kapil Gupta is working as Associate Professor in the Dept. of Mechanical and Industrial Engineering Technology at the University of Johannesburg. He obtained Ph.D. in mechanical engineering with specialization in Advanced Manufacturing from Indian Institute of Technology Indore, India in 2014. Advanced machining processes, sustainable manufacturing, green machining, precision engineering and gear technology are the areas of his interest. He has authored several SCI/ISI Journal and International Conference articles. He also authored and edited 10 international books on hybrid machining, advanced gear manufacturing, micro and precision manufacturing, and sustainable manufacturing with the renowned international publishers. He has also successfully guest edited special issues of a Scopus indexed journals and he is currently editing a series of handbooks on Advanced Manufacturing as a series editor. He is a recognized reviewer of many international journals and in the advisor/technical committees of international conferences. He has also delivered invited speeches in international conferences and symposiums, and seminar talks at international universities. Kapil Gupta is a NRF [National Research Foundation] rated Researcher in South Africa. Currently, he is supervising some postdoctoral fellows and postgraduate students who are busy conducting research in advanced manufacturing and industrial engineering fields. He has obtained PG Diploma in higher education and conducting research in engineering education. He is working on implementation of innovative teaching techniques for the enhanced learning of engineering students. Recently, he also developed a manufacturing engineering virtual lab.