Middle-East Journal of Scientific Research 25 (7): 1491-1500, 2017
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2017.1491.1500

Material Characteristic Study and Fabrication of Hydroxyapatite (HA) with Poly (Lactide/Lactic) Acids (PLA) for Orthopaedic Implants

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Abstract: Recent research and developments in the field of orthopaedic implants are in bioactive and biodegradable composite materials. The implants made out of such composite materials, structurally support the fractured bone and reabsorbed into the body during regeneration process. The composites are made from synthetic or natural fillers and polymers which are bioactive and biodegradable. The neighbouring tissues will be least affected during degradation of bioactive composites. The major biocompatible and biodegradable polymer element in aliphatic polyesters is Poly (lactide/lactic) acid (PLA). Hydroxyapatite (HA) being a member of calcium phosphate family, considered to be the best filler material for regeneration of bone. Thus, composites are made out of HA as the filler and different PLA matrix were tried in various orthopaedic implants. The paper reviews the material characteristic study and fabrication methods of composites made from different PLAs with HA. The properties of the implants can be improved by adding agents or treating HA filler materials. Hybrid composites made with nano particles are the recent advancement in orthopaedic implants.

Key words: Biodegradable・Bioactive・Biocompatible・PLA・HA and PLA/HA composite

INTRODUCTION

Over the years, various bioactive materials have been tried as orthopaedic implants, for fixation of fractured bones and hard tissues. In orthopaedic application bone grafting method is considered as standard as it easily binds to the surrounding bone [1]. Though it is considered as standard, there are few disadvantages, like mismatch due to dimensions, preparation techniques or quality of bone been grafted etc., this in turn leads to infections [1]. The disadvantages of the grafted bone are overcome by the implants which are synthetic materials used in bone regeneration process of a defective bone.

The implants are made out of metal and its alloys, ceramic, synthetic polymer and composite [1-3]. Metals and metal alloys are long being used in orthopaedic implants. They have better mechanical properties than any other material used in fixation of defective bone [2, 3]. Some of the short comings are, post surgeries may be required to remove them, uneven bone growth making surrounding areas more prone to terminal factures and release of toxic corrosion products during degradation [2, 4].

Ceramic implants recently are used extensively in clinical application. Some of them are termed as 'bioceramics' [3], as they are considered as substitutes for the human bone. Bioceramics are biocompactible, bioactive because of their structural and chemical composition resemblance to natural bone [3]. Thus, helping them in regeneration process [3, 5, 6]. Bioactive ceramics are brittle in nature, hence limits its application as orthopaedic implants in medical field.

The implants made from polymer materials are both made from natural and synthetic materials [1]. Natural polymers can interact with the surrounding cells as they are bioactive [1]. Polymers made from natural renewable sources can be called as bio-based polymers [5]. They can be biodegradable and non-biodegradable and can be

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made from extraction and separation, fermentation and conventional synthesis. Some of the synthetic polymers are biodegradable and most of them belong to polyester family [7]. The shape, size, structure, mechanical and degradation process of the synthetic polymers can be designed and made to fit the clinical requirement [7]. The disadvantage is it releases toxins and loses its mechanical properties during degradation process.

Some of the materials mentioned above have advantages and disadvantages, when preferred as implants for fixation of bone. Better results can be obtained when individual materials are combined together to form a composite. Such composites can be biocompatible, bioactive and biodegradable [3-5]. These composites can be made through mixing organic and inorganic materials [3, 5]. Recent researches are on the hybrid composites which in deed are combination of inorganic and organic biodegradable and bioactive nano materials, to produce porous natural bone structure [8, 9].

In this paper, we review the usage of bioactive, biodegradable and biocompatible polymer and filler material which when combine together resembles the natural bone structure. Fabrication, characteristics and improvement in performance of implants due adding agent or by specific treatment to the ingredients are discussed. There are many polymers and filler which are bioactive, biodegradable and biocompatible. In this situation, the focus is on most widely used polymer and filler material.

For regeneration of bone, various biocompatible and biodegradable natural (collagen, chitosan and proteins etc.) and synthetic polymers (aliphatic polyester, aliphatic-aromatic polyester and polyamides etc.) are used [10, 11]. Aliphatic polyesters are found out to be the widely-used polymer in orthopaedic implants [4, 7, 12]. They are bioactive, degradation products are not toxic and biocompatible [4, 12, 13]. During degradation process, it structurally supports and slowly transfers the load to the regenerated bone [10]. Degradation of the implants can be designed and fabricated to suit the requirements [5]. They can be made from natural and synthetic materials [13].

Filler materials are in the form of fiber, powder and nano particles, which provides both porous environment and structural support during regeneration of bone. The natural and synthetic fibers used as filler materials, are used as reinforcement materials for the composites [2]. Powdered or nanoparticle addition of ceramic materials are used for fabrication of 3D structural implants used in fixation of bone [5]. Hydroxyapatite (HA), tricalcium phosphate (TCP), bioactive glass (BG) and calcium silicate (CS) etc.[6], are the few types of ceramic used in implants. Among them hydroxyapatite (HA) considered to be the best suited one for bone regeneration process, as it resembles the natural bone.

Paper reviews the most widely used Polylactic/lactide acids (PLAs) and hydroxyapatite (HA), which are composites made from aliphatic polyester-ceramic combination. Application of hybrid materials through nanotechnology helps in more effective interaction of inorganic-organic bioactive and biodegradable materials for effective bone regeneration [5]. Specific property requirement for the implant made difficulties in manufacturing them for fixing defective bones and hard tissues. Some advanced methods like, microencapsulation, phase separation, electrospinning, 3D printing and different moulding processes etc. helps in producing the porous extracellular matrix structure. This in turn helps in close signaling of the implant with the nearby cells, leads to enhanced bone growth [6].

Biodegradable Aliphatic Polyesters: For short range application, as in orthopaedic implants biodegradable aliphatic polyesters are employed [12]. The most commonly researched synthetic biodegradable aliphatic polysters are polygycolide/glycolic (PGA), polylactide/lactic acid (PLA) and poly (lactic – co – glycolic/glycolode) acid (PLGA) 6. Classification and formation are illustrated in the (PLGA) [6]. Classification and formation are illustrated in the Fig. 1. They are formed by open ring polymerization of basic monomeric element or combination of elements [11, 12] as shown in Table 1. The basic unit of the polymer being the lactic acid and it two isomeric forms L-lactide and D – lactide [4, 12, 14]. Poly – L – lactic acid or lactide, (PLLA) consist of L-isomers and Poly – D – lactic acid or lactide, (PDLA) consist of D-isomers polymers. They combine together to form Poly – D, L lactic or lactide (PDLLA).

Physical Characteristic: Under synthetic polymers poly lactic acid (PLA), polyglycolide (PGA) and copolymer polylactic-co-glycolide PLGA are considered for regeneration of bone. Compared to PGA, poly – L – lactide (PLLA) has excellent tensile strength and Young's modulus [11, 14]. Thus it makes very much suitable as structural support in fixation of defective bone. Highest crystallinity is for PGA, hence got highest tensile modulus and very low degradation. PGA has the highest melting point and lowest being poly(DL-lactide), PDLLA [11]. PLGA as moderate glass transition temperature Tg 50-55°C, this being the major disadvantage in sterilization

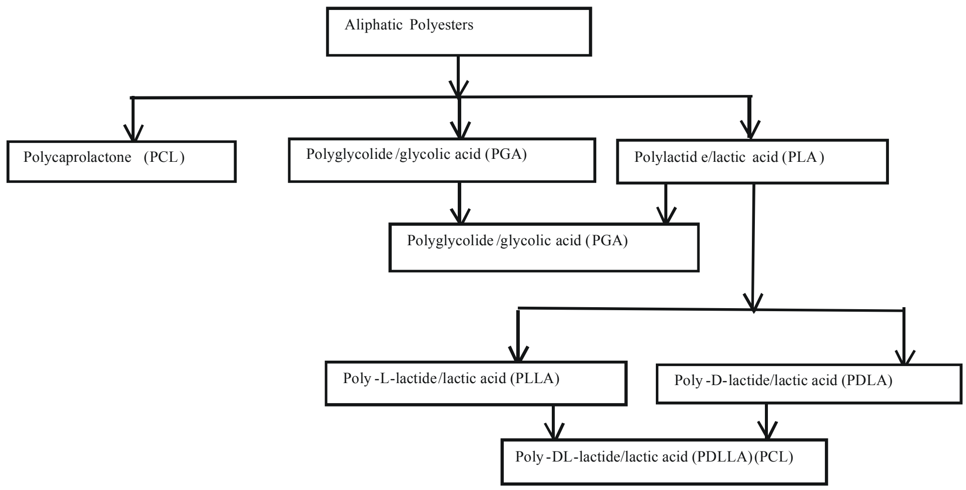

Fig. 1: Classification of different biodegradable polyesters [10-12, 16]

Table 1: Properties of Biodegradable Aliphatic Polyester [4, 5, 8, 10, 11, - 17]

Polymer	Compressive /tensile strength (MPa)	Young's Modulus (GPa)	Tensile Modulus (GPa)	Elongation (%)	Melting point (°C)	Glass transition temperature (°C)	Cristallinity (%)
Poly(L-lactic acid) PLLA	28- 2300	4.8	1.5-2.7	5-10	173-178	60-65	37
Poly(D, L-lactic acid) PDLLA	29-150	1.9	1.9	3–10	165-180	40-69	45-55
Poly(Glycolic acid) PGA	350-920	12.5	5-7	15-20	200	35-40	Amorphous
Poly(D, L-lactic-co- glycolic acid (85/15)	41.4-55.2	2.0	1.4-2.8	3-10	Amorphous	50-55	Amorphous
Poly(D, L-lactic-co- glycolic acid (75/25)	41.4-55.2	2.0	-	3-10	Amorphous	50-55	Amorphous
Poly(D, L-lactic-co- glycolic acid) (50/50)	41.4-55.2	2.0	1.4-2.8	3-10	Amorphous	45-50	Amorphous
Poly(D, L-lactic-co- glycolic acid) (90/10)						45-50	

Table 2: Properties of Biodegradable Aliphatic Polyester [4, 5, 8, 10, 11, - 17]

Monomer Polymers *Biodegradable Aliphatic*

Biodegradable Aliphatic polymers formed by ring polymerization

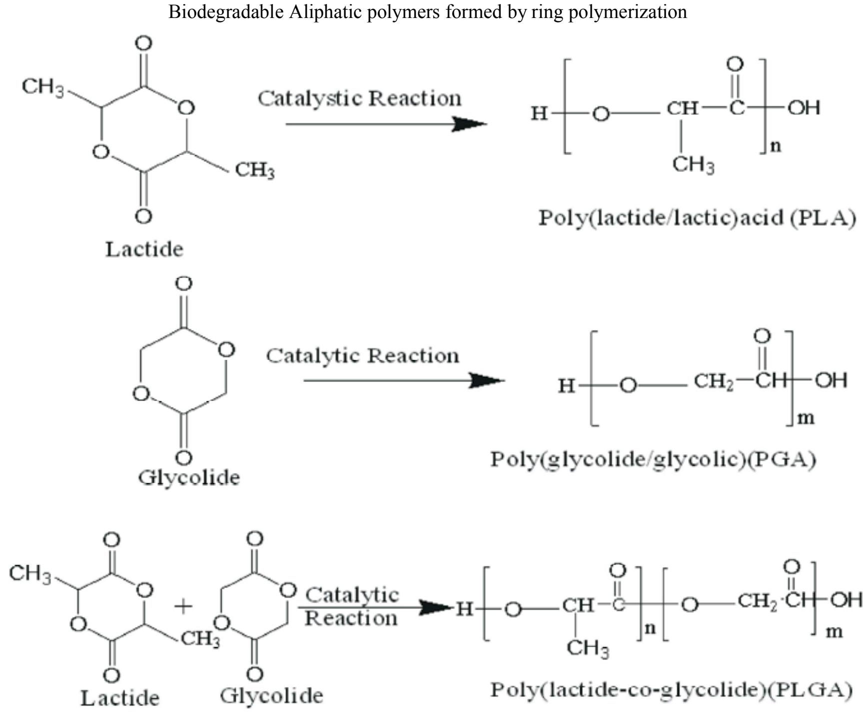

Table 3: Degradation characteristics and applications of biodegradable aliphatic polyester [4, 5, 8, 10, 14 – 17]

Polymer	Loss of strength (months)	Loss of mass (months)	Degradation Time (months)	Degradation Products	Applications
Poly(L-lactic acid) PLLA	6	4.8	>24	L-lactic acid	Suture anchors, meniscus repair, medical devices, drug delivery, orbital floor
Poly(D, L-lactic acid) PDLLA	1-2	1.9	12 - 15	Glycolic acid	Fracture fixation, interference screws, suture anchors, meniscus repair
Poly(Glycolic acid) PGA	1-2	12.5	3 - 4	D, L-lactic acid	Orthopaedic implants, drug delivery
Poly(D, L-lactic-co- glycolic acid (85/15)	1-2	2.0	3–6	D, L-lactic acid and glycolic acid	Interference screws, suture anchors, ACL reconstruction
Poly(D, L-lactic-co- glycolic acid (75/25)	1-2	2.0	1–2	D, L-lactic acid and glycolic acid	Plates, mesh, screws, tack, drug delivery
Poly(D, L-lactic-co-glycolic acid) (50/50)	1-2	2.0	3 - 6	D, L-lactic acid and glycolic acid	Orthopaedic implants, drug delivery
Poly(D, L-lactic-co- glycolic acid) (90/10)	1-2	1 - 2	<3	D, L-lactic acid and glycolic acid	

of implants [5, 11, 14]. PLGA has amorphous structure and Tg values changes as the lactic acid (LA) to glycolide (GA) polymer changes. This will lead to correction of molecular weight and also affects the mechanical and thermal properties as well [10]. The physical, mechanical and thermal properties of the polymer are illustrated in Table 2.

Degradation Characteristic: Degradation of the biodegradable aliphatic polymers are by erosion of either bulk or heterogeneous way in corpus surrounding solution [15]. There are four steps involved in degradation process. They are hydration, initial degradation, constant degradation and solubilization. The main factors influencing degradation process are molecular weight, the ratio GA to LA, stereochemistry and end group functionalization [14, 15]. Degradation product produced are lactic, glycolic, or combination of both acids [5]. The final process is break down into carbon dioxide and water [14].

Though crystallinity and other mechanical properties are high for PGA, loss of strength and loss of mass are less compared to PLLA. PGA has high degradation rate when compared to the LA/GA copolymers. And this may be due to the amorphous structure of LA/GA copolymers. Degradation characteristics and application is shown in Table 3.

Biodegradable Ceramics: There are various types of ceramics belonging to calcium phosphate family, which are structurally and mineral composition matching with the human bone and teeth [8, 9]. More researches are being done on repair and regeneration of the defective bone using bioactive and biodegradable ceramics.

Hydroxyapatite (HA), ($Ca_{10}(PO_4)(OH)_2$) [18] is the widely used ceramics in fixation of fractured bone, due to bioactive, biocompatible and biodegradation properties [19]. Tensile strength and Young's modulus of HA are 100-900 MPa and 35-120 GPa, respectively [6]. Low brittleness, fracture toughness, hardness, fabrication problems and slow degradation process are some of the disadvantages of hydroxyapatite powder (HAp). Hence, they cannot be employed alone as a structural support for repair of defective bone when used clinically 6. Nano hydroxylapatite (nHA) has some similarity features to natural bone apatite [19]. nHA shows greater interaction with neighbouring cells and thus helps in faster bone regeneration [8- 9, 19].

HA/PLA Biodegradable Composite: Natural bone consists of inorganic mineral element in an organic matrix to form an extracellular matrix (ECM) [20, 22], thus forming a complex composite. Thus achieving tissue growth and mechanical properties required for repair of bone. HA/PLA combination of inorganic-organic biocompatible, bioactive and biodegradable composites can be used in fixation of defective or injured hard tissues.

Fabrication Technique of HA/PLA Composites: Numerous fabrication techniques were used for manufacture of HA/PLA composite. They are hot molding & pressing, solvent casting, microencapsulation process, phase separation, electrospinning and advanced 3D printing & rapid prototyping techniques [10, 12, 22-29]. Some of the techniques or methods are conventional manufacturing for the polymer while others are recent advancement in manufacturing.

Hot Moulding and Pressing: Plates, rods and screws for the orthopaedic implants are made through hot injection/compression moulding process [25]. In injection moulding, the polymer granules and filler materials are powdered by milling process, dried and stored separately. Initially the thermoplastic polymer is heated to melt into liquid form, into this filler are mixed. Thus, the thoroughly mixed filler/polymer is injected into a closed mould cavity [26]. Residual stress and fiber orientation are the factors in injection moulding process [10].

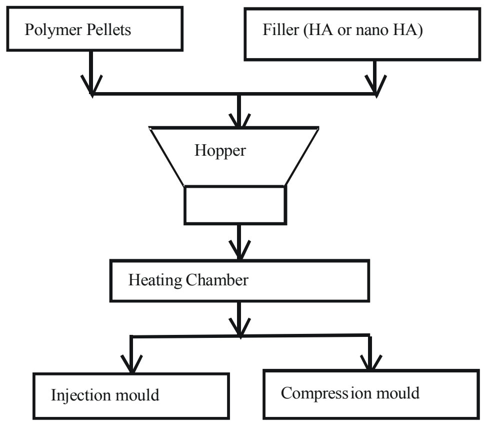

Fig. 2: Schematic sketch of Hold moulding process

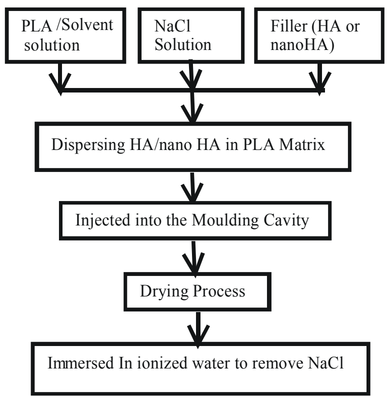

Fig. 3: Schematic sketch of solvent solution process

In compression moulding is an incorporation of hot pressing of the mixed filler/polymer in a closed mould and autoclaving [10]. After completion of moulding process, pre-heating of the moulded part on an autoclave is done to remove the solvents. The illustration of moulding process is shown in Fig. 2.

Solvent Casting: Solvent casting is most commonly used for manufacture of polymer based composites. The PLA, PGA and copolymers along with HA is dissolved in a solvent. Into the solution sodium chloride solution prepared, the aqueous PLA solution and HA/nanoHA fillers are added. Using ultrasonic liberator fillers are dispersed in PLA solution [30]. This residue is being casted into moulds. The casting is dried and the sodium crystals are dissolved by immersing in de-ionized water for some time [25]. Fig. 3 shows the schematic solvent casting process representation. Salt leaching leads to production of porous, 2D or 3D structures [22]. The bone regeneration process is accelerated, by fast tissue growth inside the porous cavities.

Microencapsulation Process: Microencapsulation is a process in which, the hydrophilic content of the polymer is evaporated. Microspheres and microcapsules are prepared by this method. Technique employees the adding HA and PLA emulsion of oil/water or water/oil emulsion and agitated thoroughly to form microspheres [22]. Stabilizers are used to control the size of the microspheres. HA/PLA microspheres formed exhibit properties required for filler materials for bone fixation [22]. Drug delivery and proteins are done with micro particles [25].

Thermally Induced Phase Separation (TIPS) (Freeze-Drying Method): Thermal induced phase separation method or freeze-drying in which the temperature decreases there will be a decrease in effectiveness of the solvent. On cooling a solvent at higher temperature, the different phases are formed. One with rich phase and other with lean phase are formed [31, 32]. Homogeneous polymer solution when treated thermally becomes unstable thermodynamically and produces different phases. One phase having high polymer content and the other having less. And removal of the solvent from the rich polymer density phase, to produce porous structures. 3D porous structures are produced by this method. Nano HA/PLGA are produced using phase separation process, the pores are closed by increasing the content of HA [22]. Schematic thermally induced phase separation (TIPS) is shown in Fig. 4.

Electrospinning Process: Electric force is applied to separate or disperse the HA in the aqueous solution in this process. The solution having HA inside the polymer moving from the tip of the injector is repelled by the external electric field. Thus, elongated HA particle along with the solution is deposited on a substrate [28]. Large surface area, high porosities and easy in making functional elements are the feature of this process [22]. It was noticed that electrospinning of nanoHA/PLA on fiber substrate lead to reduction in fiber size [22, 30]. Fig. 5 shows the schematic diagram of electrospinning process.

3D Printing & Rapid Prototyping Technologies: CAD/CAM technologies and rapid prototyping techniques were used to make 3D orthopaedic implants. The restoration of complex and specific hard tissues requires tailored made implants, for particular situation. The processes are used to manufacture implants specific for a patient. Process of manufacturing employees various rapid prototyping technologies like fused deposition method, selective laser sintering, stereolithography, 3D plotting and Bioprinting etc. [23]. HA/PLA implants made from unmodified consumer grade - 3D printers are high in quality [29]. Initially 3D CAD models prepared from CT scans or MRI scans. Slicing 3D models and converting into 2D models. Layer by layer manufacturing is adopted to produce 3D bio-implants using 3D printing technology. Finally, any post processing techniques are applied to produce a complete bone structure and features [23]. Fig. 6. shows the process flow diagram of 3D printing & Rapid prototyping technologies.

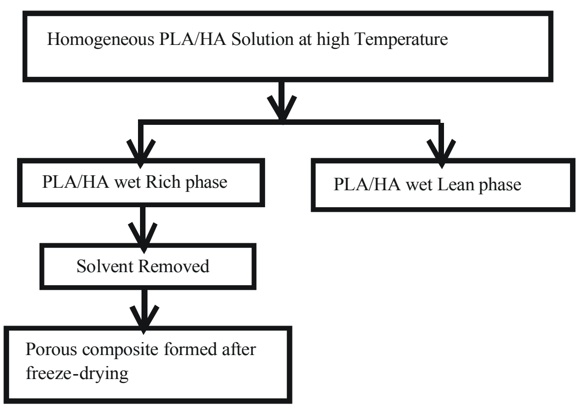

Fig. 4: Schematic sketch of Thermally Induced Phase Separation (TIPS) process

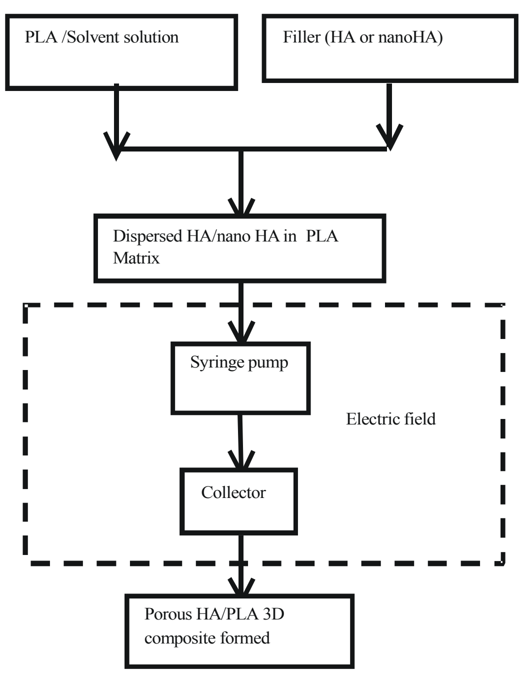

Fig. 5: Schematic sketch of electrospinning

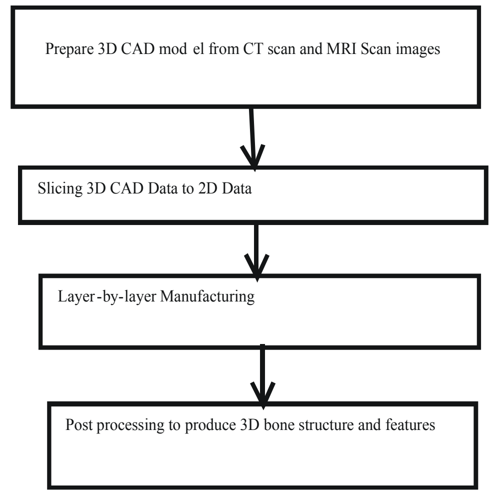

Fig. 6: Schematic sketch of 3D Printing and Rapid Prototyping Technologies Schematic sketch of 3D Printing and Rapid Prototyping Technologies

Physical Characteristics of HA/PLA Composite: The HA/PLA composites should meet the sufficient mechanical and physical properties for the orthopaedic implants. The tensile and percentage elongation of HA/PLA composite decreases as increase in weight percent of HA. The tensile modulus increase on increasing weight percent of HA [33]. SEM micrograph images shows at higher weight content of HA, agglomerate and void are formed in HA/PLA composite [34]. Molecular weight, crystallinity and the orientation are factors affecting the mechanical properties of HA/PLA composite [35]. Needle like nano HA shows better crystallinity and surface area compared to powder HA [36].

Mechanical properties such as bending stress, modulus elasticity and stress were studied on polylactic acid (PLA) composite with hydroxyapatite fibers(HAF) [37]. TABLE IV shows the result obtained for different weight percentage of hyroxyapatite fiber (HAF). Bending stress at increases as the weight percentage increases to 20 and after that it decreases. Initially bending stress measured perpendicular to the hot pressing axis. Not much difference measured when measurements taken parallel to the hot pressing axis. Modulus of elasticity is higher as the HAF weight percentage increases. The maximum stress value is for 20% weight of HAF fiber and shows a decrease on stain value as the weight percentage of HAF increases. The mechanical property change happens when these is a change in weight percentage of matrix phase.

Table 4: Mechanical properties of Hydroxyapatite/Poly-L-lactide (HA/PLLA) made from different hot pressing time [38]

Time of hot pressing (min)	Crystallinity %	Compressive Strength (MPa)	Modulus E (Gpa)
0	35		
5	36		
15	29	115	4
30	26	130	5
45	24		
60	21	140	10

Table 5: Mechanical properties of Hydroxyapatite/Poly-L-lactide (HA/PLLA) made from different hot pressing time [38]

Time of hot pressing (min)	Crystallinity %	Compressive Strength (MPa)	Modulus E (Gpa)
0	35		
5	36		
15	29	115	4
30	26	130	5
45	24		
60	21	140	10

Table 6: Mechanical properties of various weight percentages of Poly-D-L-Lactide/nano-Hydroxyapatite (PDLLA/nHA) for different soaking time in Simulated Body Fluid (SBF) [39]

	Weight Loss %				Compressive strength MPa				Compressive modulus MPa			
Incubation Time (days)	0	20	40	60	0	20	40	60	0	20	40	60
0	0	0	0	0	1.48	1.60	2.08	2.45	51.54	66.17	77.83	91.11
7	1.3	1.6	2.0	3.3	1.50	1.64	1.9	2.19	47.67	56.88	63.11	84.80
14	1.7	2.0	3.0	3.6	1.49	2.20	2.37	2.70	43.26	63.86	70.36	79.57
28	1.9	2.2	4.2	4.1	1.57	2.26	2.48	3.22	28.54	68.68	80.61	73.54

Biocomposite materials were prepared in the form of laminates with hdroxyapatite (HA) and poly –L-Lactide (PLLA) [38]. TABLE V gives the Crystallinity, modulus of elasticity and compressive are studied for various hot pressing time HA/PLLA composite laminates. Initially there is a slight increase in crystallinity and a decrease in 40% as the hot processing time increases. Compressive strength and modulus of elasticity increases as the time of hot processing increased.

Table 6 shows the mechanical properties of various weight percentages of nano-hydroxyapatite (nHA) with poly – D-L- lactide (PDLLA) composite while soaking on simulated body fluids (SBF) different period of time [39]. More weight loss is noticed for 60% weight of nHA. And also there is a significant difference in weight loss for 60% nHA than with 20% and 30% nHA when incubated for 28 days in SBF. There is a considerable difference in compressive strength and compressive modulus for 20%, 40% and 60% weight of nHA. The pore size is more for 60% weight of nHA compared other less weight percentage nHA. Degradation rate increases as the pore size increases as immersed in SBF for long time. Hence the will be decrease in mechanical properties as the incubation time increases in SBF.

Property Improvement by Adding Agents or Treated Filler Materials: Natural bones formed by inter linking inorganic mineral apatite and organic collagen by proteins. Additives/adding the interaction with the organic phase of the polymer. HA is used as coating for the reinforced fiber /polymer matrix, triggering fast bone formation during the growth of tissues [42]. HA/PLA has lesser strength compared to a bone, hence addition of biodegradable fibers will increase the physical properties of the implants [24]. Alkaline, silane, etc. are some of the treatment for fibers in PLA matrix [43]. Strength of the PLA/HA composite is improved by the application of surface initiated polymerization and phosphonic acid coupling agent or treatment of the filler materials are used to improve [44].

Table 7 gives the thermal and mechanical properties of scaffolds made out of hydroxyapatite/poly (L-lactide acid) (Hap/PLLA) combined with silica nano particles [40]. Not much significant decrease in thermal property is noticed. Young's modulus E increases on addition of silicon nano particles. Porosity of the scaffolds shows a marginal increase when immersed in simulated body fluid (SBF) for 7 days was noticed for pure PLLA. The scaffolds made with 10% Hap and 0.5%silica nano powder shows decrease in porosity and mechanical properties when soaked in SBF for 14 days.

Table 7: Thermal and Mechanical property of hydroxy apatite reinforced poly(L-lactide acid) composites with silica nanoparticles [40]

	Tg (°C)	Tm (°C)	xc (%)	E (Mpa)
PLLA	69.3	181.1	42.1	5.3
PLLA/HA 90/10	68.9	18.1.4	43.2	5.0
PLLA/HA/ Sio2 90/9.5/0.5	67.4	181.1	44.4	7.0

The porosity effect on the mechanical properties of carbon fibers(CF) nano- hydroxyapatite (nHA)/ polylactide (PLA) is studied [41].Bending strength and bending modulus decreases as the porosity level increases inside the composites. Different composites with porosity range from 0%, 20%, 60% and 80% are made and studies for mechanical behaviour. Stress and strain decreases on increase in porosity levels.

Nano and Hybrid Composites: Implants which are bioinert, bioactive and biodegradable are weak in physical properties due the high porosity levels. Combination of nano inorganic-organic hybrid composites is made better property response inside the human tissues. Different organic materials like, chitosan, collagen and caprolactone etc.[18, 45, 46] are tried along with HA/PLA composite. Inorganic materials like monntmorillonite nanoclay (MMT), tricalcium phosphate, etc. are tried with polymeric matrix to mimic the bone structure and properties [8, 24].

CONCLUSION

Replication of a hard tissue, defective or damage bone is very much challenging. PLLA polymer found to be the most apt biodegradable polymer for implant materials. Out of all inorganic filler material, HA having the most structural and chemical resemblance with natural bone Nano hybrid composite combines all individual advantages of materials which otherwise not sufficient to meet the properties required in orthopaedic application. Restoration and regeneration process requires porous cavities for signaling bone growth. Implants are tailored made using advanced manufacturing technologies like electrospinning and 3D printing to meet the specific, shape, size and property requirement.

For orthopaedic implant require porous scaffolds. When the porosity increases the mechanical load carry capacity is greatly reduced. The degradation property of the implants are studied by immersing in simulated body fluid (SBF) for 28 days. Decrease in mechanical property and increase in porosity levels are noticed. The porosity levels leads to the high connectivity of the bone cells, which will trigger the fast self-healing of the fractured bone. Bending and compressive stresses are studied extensively, which shows the importance mechanical character for the biocompatible, bioactive and biodegradable implants.

REFERENCES

1. Elena Gracia-Gareta, Melanie J. Coathup and Gordon W. Blunn, 2015. Osteoinduction of bone grafting materials for bone repair and regeneration, Bone., 8: 112-121.
2. Hoi-yan Cheung, Mei-po Ho, Kin-tak Lau, Francisco Cardona and David Hui, 2003. Natural fibre-reinforced composites for bioengineering and environmental engineering applications, Composites: Part B, 40(8): 655-663.
3. Min Wang, 2003. Developing bioactive composite materials for tissue replacement, Biomaterials, 24(13): 2133-2151.
4. Samson Oluropo Adeosun, Ganiyu Ishola Lawal and Oluwashina Philips Gbenebor, 2014. Characteristics of Biodegradable Implants, J. Minerals and Materials Characterization and Engineering, 2: 88-106.
5. Bedilu A. Allo, Daniel O. Cosra, S. Jeffrey Dixon, Kibret Mequanint and Amin S. Rizkalla, 2014. Bioactive and Biodegradable Nanocomposites and Hybrid Biomaterials for bone regeneration, J. Functional Biomaterials, 3: 432-463.
6. Chengde Gao, Youwen Deng, Pei Feg, Zhongzheng Mao, Pengjian Li, Bo Yang, Junjie Deng, Yiyuan Cao, Cijun Shuai and Shuping Peng, 2014. Current progress in bioactive ceramic scaffolds for bone repair and regeneration, Int. J. Mol. Sci, 15(3): 4714-4732.
7, Pathiraja A. Gunatillake and Raju Adhikari, 2003. Biodegradable synthetic polymers for tissue engineering, European Cells and Materials, 5: 1-16.
8. Sergey V. Dorozhkin, 2011. Biocomposites and hybrid biomaterials based on calcium orthophosphates, Biomatter, 1: 3-56.
9. Sergey V. Dorozhkin, 2009. Calcium orthophosphate-based biocomposites and hybrid biomaterials, Journal Material Science, 44(9): 2343-2387.
10. Me-po HO, Hao Wamg, Joong-Hee Lee, Chun -kit Ho, Kin- tal Lau, Jisong Leng and David Hui, 2012. Critical factors on manufacturing processes of natural fibre composite, Composites: Part B, 43(8): 3549-3562.

11. Azadehsadat Hashemi Doulabi, Kibret Mequanint and Hadi Mohammadi, 2014. Blends and Nanocomposite Biomaterials for Articular Cartilage Tissue Engineering, Materials, 7(7): 5327-5355.
12. Dimitrios N. Bikiaris, 2013. Nanocomposites of aliphatic polyesters, A overview of the effect of different nanofillers on enzymatic hydrolysis and biodegradation of polyester, Polymer Degradation and Stability, 98: 1908-1928.
13. Ramesh P. Babu, Kevin O'Connor and Ramakrishna Seeram, 2013. Current progress on bio-based polymers and their future trends, Progress in Biomaterials, 2(8): 1-16.
14. Marco A. Velasco, Carlos A Narvaez-Tovar and Diego A. Garzon- Alvarado, 2015. Design, materials and mechanobilogy of biodegradable scaffolds for bone tissue engineering, BioMed Research Internationa, pp: 1-21.
15. Piergiorgio Gentile, Valeria Chiono, Irene Carmagnola and Paul V. Hatton, 2014. An overview of Poly(lactic -co-glycolic) Acid (PLGA) based Biomaterials for bone tissue engineering, Int. J. Mol. Sci., 15(3): 3640-3659.
16. Gurunathan, T., Smita Mohnty and Sanjay K. Nayak, 2015. A review of the recent developments in biocomposites based on natural fibres and their application perspectives, Composites: Part A, 77: 1-25.
17. Neuendorf, R.E., E. Saiz, A.P. Tomsia and R.O. Ritchie, 2008. Adhesion between biodegradable polymers and hydroxyapatite: Relevance to synthetic bone-like materials and tissue engineering scaffolds, Acta Biomaterialia, 4(5): 1288-1296.
18. Xuan Cai, Hua Tong, Xinyu Shen, Weixuan Chen, Juan Yan and Jiming Hu, 2009. Preparation and characterization of homogeneous chitosan-polylactic acid/hydroxyapatite nanocomposite for bone tissue engineering and evaluation of its mechanical properties, Acta Biomateialia, 5(7): 2693-2703.
19. Prof. Ning Hu, 2012. Composites and Their Application, Croatia: InTech. - Open science/Open Mind, pp. 114-140.
20. Rayan K. Roeder, Gabriel L. Converse, Robert J. Kane and Weimin Yue, 2008. Hydroxyapatite-reinforced polymer Biocomposites for synthetic bone substitues, Biological Material Science, 60(38): 38-45.
21. Graham G. Walmsley, Adrian McArdle, Ruth Tevlin, Arash Momeni, David Atashroo, Michael S. Hu, Abdullah H. Feroze, Victor W. Wong, Peter H. Lorenz, Michael T. Longaker, Derrick C. Wan, 2015. Nanotechnology in Bone tissue Engineering, Nanomedicine: Nanotechnology, Biology and Medicine, 11(5): 1253-1263.
22. Huan Zhou, Joseph G. Lawrence and Sarit B. Bhaduri, 2012. Fabrication aspect of PLA-CaP/PLGA-CaP composites for orthopaedic applications: A review, Acta Biomaterials, 8(6): 1999-2016.
23. Helena N. Chia and Benjamin M. Wu, 2014. Recent advances in 3D printing of biomaterials, Journal of Biological Engineering, 9(4): 1-14.
24. Mohammad R. Kaiser, Hazleen B. Anuar, Noorasikin B. Samat, Shamsul B. Abdul Razak, 2013. Effect of processing routes on the mechanical, thermal a nd morphological properties of PLA-based hybrid biocompoiste, Iran Polymer Journal, 22: 23-131/
25. Mauli Agrawal, C., Gabriele G. Niederauer and Kyriacos A. Athanasiou, 1995. Fabrication and Characterization of PLA-PGA Orthopedic Implant, Tissue Engineering, 1(3): 241-253.
26. Simpson, R.L., S.N. Nazhat, J.J. Blaker, A. Bismarck, R. Hill, A.R. Boccaccini, U.N. Hansen and A.A. Amis, 2015. A comparative study of the ffects of different bioactive - mechanical and in vitro investigation, Journal of the Mechanical Behavior of Biomedical Materials, 50: 277-289.
27. Adnan Haider, Kailash Chandra Gupta and Inn-Kyu Kang, 2014. PLGA/nHA hybrid nanofiber scaffold as a nanocargo carrier of insulin for accelerating bone tissue regeneration, Nanoscale Research Letter, 9(1): 1-12.
28. Lihong Lao, Yingjun Wang, Yang Zhu, Yuying Zhang and Changyou Gao, 2011. Poly(lactide-co-glycolide)/hydroxyapatite Nanofibrous scaffolds fabricated by electrospinning for bone tissue engineering, Journal of Materials Science: Materials in Medicine, 22(8): 1873-1884.
29. Artem B. Kutikov, B.S. Anvesh Gurijala and Jie Song, 2014. Rapid Prototyping Amphiphilic Polymer / Hydroxyapatite Composite Scaffolds with Hydration - Induced Self – Fixation Behavior, Tissue Engineering: Part C, 21(3): 1-13.
30. Xueyu Qiu, Yadong Han, Xiuli Zhuang, Xuesi Chen, Yuesheng Li and Xiabin Jing, 2007. Preparation of nano- hydroxyapatite/poly(l- lactide) biocomposite microspheres, Journal of Nanoparticle Research, 9(5): 901-908.

31. Fangfang Sun, Hongjian Zhou and Jaebeom Lee, 2011. Various Preparation methods of highly porous hydroxyapatite/polymer nanoscale biocomposite for bone regeneration, Acta Biomaterialia, 7(11): 3813-3828.
32. Aurelio Saletno, Mar Fernandez, Gutierrez, Julio San Roman del Barrio and Concepcion Domingo Pascual, 2014. Macroporous and nanometer scale fibrous PLA and PLA-HA composite scaffolds fabricated by a bio safe strateg, RSC Advance, 4: 61491-61502.
33. Nainar, S.M., Shahida Begum, M.N.M. Ansari and Hazleen Anuar, 2014. Tensile Properties and Morphological Studies on HA/PLA Biocomposites for Tissue Engineering Scaffolds, International Journal of Engineering Research, 3(3): 186-189.
34. Huinan Liu and Thomas J. Webster, 2010. Mechanical properties of dispersed ceramic nanoparticles in polymer c omposites for othopeadic applications, International Journal of Nanomedicine, 5: 299-33.
35. Xingxun Liu, Tongxin Wang, Laurence C. Chow, Mingshu Yang and James W. Mitchell, 2014. Effects of Inorganic Fillers on the Thermal and Mechanical Properties of Poly(lactic acid), Int. J. Polym. Sci., pp: 1- 17.
36. Jiang Liuyun, Xiong Chengdong, Jian Lixin and Xu Lijuan, 2014. Effect of hydroxyapatite with different morphology on the crystallization behaviour, mechanical property and in vitro degradation of hydroxyapatite/ poly(latic-co-glycolic) composite, Composites Science and Technology, 93: 61-67.
37. Toshihiro Kasuga, Yoshio Ota, Masayuki Nogami, Yoshihiri Abe, 2001. Preparation and mechanical properties of polylactic acid composites containing hydroxyapatite fibers, Biomaterials, 22(1): 19-23/
38. Nenad Ignjatovic, Dragan Uskokovic, 2004. Synthesis and application of hydroxyapatite/ polylactide composite biomaterial, Applied Surface Science, 238(1-4): 314-319.
39. Ling chen, Chak Yin Tang, Chi Pong Tsui, Da Zhu Chen, 2013. Mechnical properties and in vitro evaluation of bioactivity and degradation of dexamethasone – releasing poly – D- L- lactide/nano-hydroxyapatite composite scaffolds, J. the Mech. Behav. of Bio. Mater.l, 22: 41-50.
40. Samuele Guerzoni, Harmony Deplaine, Jamal El Haskouri, Pedro Amoros, Manuel Monleon Pradas, Ulrica Edlund and Gloria Gallego Ferrer, 2014. Combination of silica nanoparticles with hydroxyapatite reinforces poly(L-lactide acid) scaffolds without loss of bioactivity, Journal Bioactive and Compactible Polymers, 29: 15-31.
41. Liao Xiao-ling, Xu Wen –feng, Wang Yuan-liang, Jia Bi, Zhou Guan -yu, 2009. Effect of prous structure on mechanical properties of C/PLA/nano-HA composites scaffold, Transaction Nonferrous Metals Society if China, 19(3): 748-741.
42. Lyndon F. Charles, Erica R. Kramer, Montgomery T. Shaw, James R. Olson and Mei Wei, 2013. Self-reinforced composites of hydroxyapatite –coated PLLA fibers: Fabrication and mechanical characterization, Journal of the Mechanical Behavior of Biomedical Materials, 17: 269-277.
43. Prof. Ning Hu, 2013. ‘Composites and Their Application’, Croatia: InTech. - Open science/Open Mind, pp: 41-59.
44. Tongxin Wang, Laurence C. Chow, Stanislav A. Frukhtbeyn, Andy Hai Ting, Quanxiao Dong, Mingshu Yang and James W. Mitchell, 2011. Improve the Strength of PLA/HA Composite Throug.h the Use of Surface Initiated Polymerization and Phosphonic Acid Coupling Agent, J. Res. Natl Inst Stand Technol., 116(5): 785-796.
45. Wei Hao, Jinlei Dong, Ming Jiang, Junwei Wu, Fuzhai Cui and Dougsheng Zhou, 2010. Enhanced bone fabrication in large radial defects by combining adipose-drived stem cells expressing bone morphogenetic protein 2 with nHA/RHL/PHLC/PLA scaffold, International Orthopaedics, 34: 1341-1349.
46. Bahman Torabinejad, Jamshid Mohammadi-Rovshandeh, Seyed Mohammad Davachi and Ali Zamanian, 2014. Synthesis and characterization of nanocomposite scaffolds based on triblock copolactone and nano-hydroxyapatite for bone tissue engineering, Material Science and Engineering C, 42: 199-210.