TRYAKSH INTERNATIONAL JOURNAL OF MEDICAL AND CLINICAL CASE STUDIES (TIJMCCS)
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Geopolymer Composites for Bone Tissue Application: A Short Overview

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Abstract

Geopolymer composites have been widely used for several applications including building materials, composites for thermal applications, aviation applications etc. and many more. However, the applications of these materials are not studied extensively for biomedical applications, especially for bone tissue (osseous tissue) engineering. Therefore, this study is conducted to examine the potential of geopolymers in biomedical applications reviewing the conducted experimental investigations. The conclusions from this investigation explicate that the geopolymers can be used for bone tissue engineering applications but precise attention must be given to formulate its biocompatibility and osteoconductive performances.

Keywords: Geopolymers; Biomedical Application; Bone Tissue; Biocompatibility

1. INTRODUCTION

The term "Geopolymers" basically refers to concrete and building materials and it is obvious due to its wide application in construction filed. In the early 70s (1970), Joseph Davidovits, a French chemist first coined the term "Geopolymers" to call these aluminosilicate minerals. Since then, several research studied have been executed to study geopolymers for various applications. In specific, cementless building materials [1-3], fire-resistant coating [4] and composites [5], high strength composites for jet aircraft and motor vehicle applications [6], and many more.

However, the applications of geopolymers in biomedical engineering are insignificant. Though geopolymers exhibit several potential characteristics to be used in bone tissue engineering, due to limited research in this filed and challenges regarding its biocompatibility [7] and osteoconductive performances its wide applications is not yet possible. The aluminosilicate precursor such as metakaolin, fly ash, blast furnace slag, rice husk ash, ferrochrome ash and other source materials from the various geological or industrial origin are widely used for the production of geopolymer composites (GC), but while considering for the biomedical applications, strict attention must be given on the origin of precursor material for composite synthesis. Therefore, materials with no heavy metal or toxic substances shall be used for the composite preparation, though it is widely accepted that GC immobilizes the toxic or heavy metals inside its composite matrix [8], there exists a potential threat of leach out of those materials (especially Cr, Pb or Ni etc.) in human body fluid that could cause serious health issues.

Moreover, the attainment of very less mechanical strength as compared to the other bone-like implant material in ambient temperature conditions also stands as a limiting factor for GC's wide acceptance, to irradiate this impediment in GC, some studies recommended adding some white Portland cement (WPC) [9]. However, the high alkalinity of GC is another big challenge, to control or minimize the alkalinity of GC to a limit by considering the biocompatibility factors heat treatment is adopted in GC [7, 10]. Some studies also stated that the concentration of Al in the GC must be taken care of since free "Al" has an adverse effect on the human body, it is suggested to keep its concentration low in the precursors while synthesizing GC [10]. Though there is very limited research conducted in this regard, this study has made an effort to optimize the results obtained with insight on the challenges and opportunities considering GC as a biomaterial.

2. SYNTHESIS OF GC

In general aluminosilicate materials and alkaline activator are used to synthesize GC. The choice of the source material is dependent on the application of GC, for biomedical applications only metakaolin is used so far [7, 9, 11, 12], the choice is based on the fact that it is the cheapest alumino-silicate that available in high purity form. Both sodium and potassium-based alkaline activator can be used in making GC for bone tissue engineering applications. But, some study claimed that the potassium-based geopolymers perform significantly great in vitro and in vivo and they show high bioactivity or biocompatibility [10, 13]. The optimized synthesis parameters of GC for application in the biomedical application are depicted in Table-1.

Table 1: Synthesis parameters of GC as a biomaterial**.**

Source materials	Activators	Si/Al ratio	Synthesis factors	Reference
Metakaolin	NH and NS	1.17-1.39	NS/NH =2.0; liquid/solid ratio = 0.4 and after 14 days of curing at 40°C heat treatment at 500°C for 1hr.	7
Microsilica powder	KH and KS	31	Cured at 60°C for 150 mins then heated at 250°C and 500°C for 2hr.	10
Metakaolin	NH and NS	2.10	Ambient temperature synthesis	11

3. DISCUSSIONS AND RECOMMENDATIONS

It is important to note that the GC needs to satisfy various parameters to be used as a biomaterial for bone tissue engineering. The major problems associated with the GC for successive biomedical application is its high pH values and susceptibility of the liberation of free "Al" from the GC matrix. As a result, both of these issues severely impact the biocompatibility of GC, thus making it considerably challenging for practical applications. To address these challenges, Oudanesse et al. synthesized GC having amorphous potassium-poly(sialate)-nanopolymer type gel structure taking micro silica powder with a mole ratio Si:Al = 31:1 [10]. They have taken a very minute amount of Al in GC preparation considering the hazardous effect of Al in the human body and also treated the prepared GC at high temperature (250 and 500°C) to optimize the pH of resulted composites. From the microstructural observations (see Figure 1), it could be observed that the high-temperature treatment had caused a porous microstructure which is similar to that of the natural bone tissues (see Figure 2), similar observations with elevated temperature was observed by Sayed et al. (see Figure 3). Such increment in porosity of the GC due to elevated heat may be due to water loss in the composite matrix (release of both physical and chemical water), forming the micro-pores which resulted in increase in the total porosity [7]. In the other hand the heat treatment had a positive impact of mechanical strength and geopolymer network, and it is reported that thermal treatment helps altering the structural geopolymer network, which could lead to the stabilization of the free alkali present in the composite system [10].

Figure 1: Microstructure of GC (A) no heat treatment (B) at 250°C (C) at 500°C (Oudanesse et al.[10]).

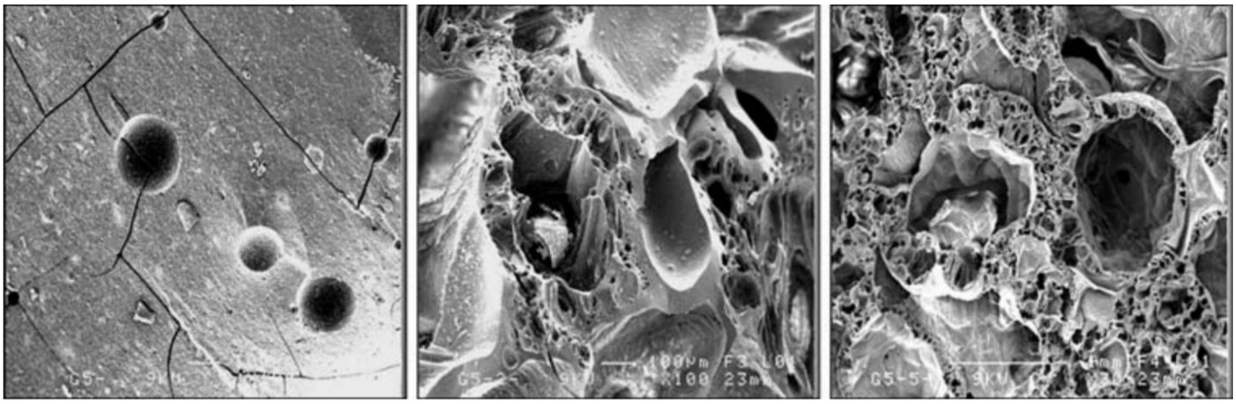
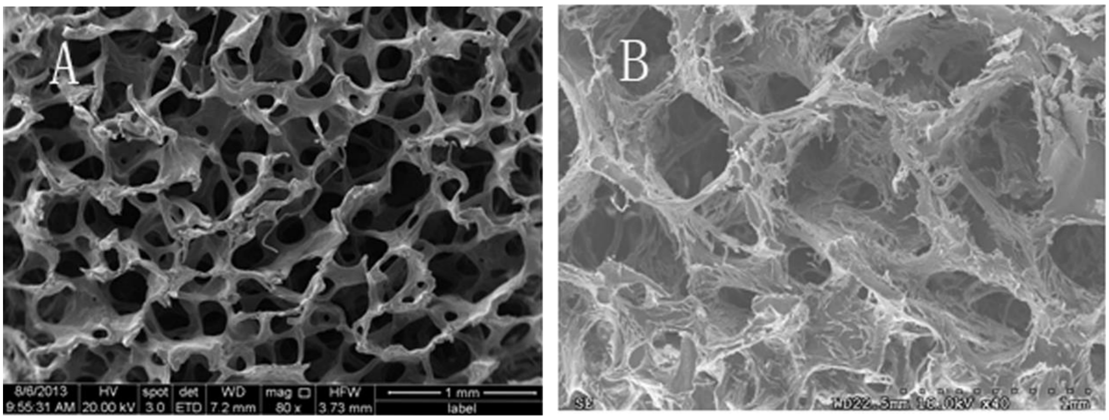
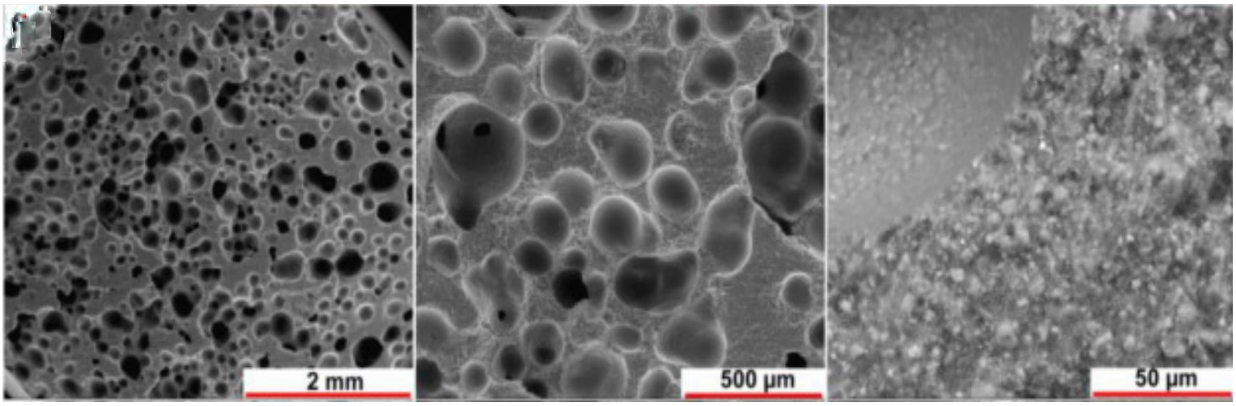


Figure 2: Microstructure of bone tissue (Wang et al.[14]).



Sayed et al. mixed different percentages of hydrogen peroxide (H_2O_2) as a foaming agent from 0 to 6 vol%, and the geopolymer specimens were denoted as B, 1.5H, 3H, 4.5H and 6H, respectively (where the numbers before the denotations indicate the % of HP added to the GC [7]. Corresponding to the obtained results of study conducted considering the porosity and mechanical properties of the produced samples, the composition with 4.5 vol% H_2O_2 addition exhibited adequate standards in terms of open porosity (71 vol%) and mechanical properties (3.56 ± 0.27 MPa) to be considered as 3D scaffold for biomaterial applications. The microstructure of the selected composition is presented in Figure 3, and it can be noticed that the internal morphology of the GC is quite similar to that of earlier one (Figure 1). Therefore, it was nominated to synthesize samples for conducting the assessment of bioactivity and biocompatibility behavior through in-vitro tests. All of the discussed studies claimed that the GC has the competency to be used as a biomaterial in hard tissue engineering applications, however more focus shall be given on the biocompatibility and structural stability of GC during practical applications.

Figure 3: Microstructure of GC (4.5H) before firing (Sayed et al.[7]).



Considering the potential of GC in biomaterials, the availability of research in this area is very limited which is, in turn, causing restraints for broad application of GC in the medical science field. Hence more research in this filed is needed to establish GC as a viable material for bone tissue engineering applications.

4. Acknowledgements

Mr. Subhabrata Mishra (CTO) and Mr. Malaya Kumar Jena (CMO) of Green Tech Concrete and Research (GTCR), Bhubaneswar, India are highly acknowledged for their support regarding this study.

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Citation: Shaswat Kumar Das and Syed Mohammed Mustakim "Geopolymer Composites for Bone Tissue Application: A Short Overview" Tryaksh International Journal of Medical and Clinical Case Studies (TIJMCCS)" Volume 1, Issue 1, 2020, pp. 1-4.

Received Date: 06th July 2020; **Accepted Date:** 10th July 2020; **Published Date:** 22nd July 2020