STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Special Issue 2, 2026
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

Exploring the Dynamic Mechanical Analysis and Biocompatibility of Compression-Molded PMMA for Biomaterial Applications

S. Baskar[1,*], R. Rajappan[2], V. Pugazhanthi[3], P. Ashok kumar[4], N. Ramanan[5], J. Srinivas[6]

Abstract

Metals such as titanium, cobalt, and magnesium are commonly used as biomaterials. However, their use can lead to tissue reactions due to the formation of foreign bodies which may cause blood cancer. Researchers have addressed this issue by substituting biomaterials with polymethyl methacrylate materials (PMMA). The PMMA material being studied is produced using the compression molding technique. This article examines the mechanical properties and biotoxicity of PMMA. These materials have undergone several mechanical analyses, including flexural, tensile, and impact tests with a particular focus on their DMA and Bio toxic behavior. The mechanical behavior of PMMA indicates higher ductility in tensile, impact, and flexural, and it also exhibits high tangential loss with mass loss characteristics in the DMA test. Additionally, simulation analysis using FEA software, such as Ansys Workbench, simulated the prototype of the hip joint, and fracture surface analysis using SEM evaluation was carried out. Finally, the bio-toxic test was analyzed to determine the biocompatibility of PMMA. Therefore, the research will focus on the application of biomaterials, particularly on hip joint functionality. Polymethyl methacrylate (PMMA) was developed via compression molding to overcome limitations of metallic biomaterials. Mechanical tests (tensile, flexural, impact, DMA), FEA simulation, and SEM fracture analysis revealed PMMA's ductility, strength, and controlled mass loss. Biotoxicity evaluation confirmed its cytocompatibility, highlighting PMMA as a promising alternative for hip joint implants with potential for future surface modification and clinical validation.

Keywords: PMMA, compression molding, mechanical behavior, DMA analysis, FEA, bio-toxic analysis

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Received Date: September 17, 2025
Accepted Date: November 06, 2025
Published Date: April 08, 2026

Citation: S. Baskar, R. Rajappan, V. Pugazhanthi, P. Ashok kumar, N. Ramanan, J. Srinivas. Exploring the Dynamic Mechanical Analysis and Biocompatibility of Compression-Molded PMMA for Biomaterial Applications. Journal of Polymer & Composites. 2026; 14 (Special Issue 2): S482–S499p.

INTRODUCTION

A composite is a substance created by blending two or more distinct substances having unique physical or chemical features. The final product has distinct qualities that set it apart from its constituent parts. Unlike mixes or solid solutions, the components of composites remain separate within the final structure. The following text has been corrected and rephrased for clarity: The new material has several advantages over traditional materials in terms of strength, weight, and price. Concrete, which is the most used artificial composite material, is created by binding loose stones (aggregate) together using a cement matrix. The bio-implant is an inexpensive material that can withstand high compressive stresses without breaking. Polywater was used to make it. Diwakar Padalia investigated the production and examination of nanocomposites composed of

PMMA and Cerium-doped Barium Titanate. These materials can be used in electric stress control devices and integral thin-film capacitors. Cerium doping was used to develop a $BaTiO_3$ system with low loss and fine grains. The PMMA shell encapsulating the $BaTiO_3$ nanoparticles is an insulator that hinders the movement of charge carriers within the nanocomposites. This makes them more effective than conventional composites in terms of reduced dielectric loss. The researchers synthesized Cerium-doped $BaTiO_3$Nano fillers via a solid-state method and generated different polymer nanocomposites by evaporating the solvent. The polymer nanocomposites were exposed to 2.4 GHz microwaves and had 30% weight-for-weight filler. According to the study, altering the Ce-doping in $BaTiO_3$Nano filler can improve the thermal and dielectric characteristics of the resulting nanocomposites. The researchers also studied the impact of microwave heating on the thermal stability of polymer nanocomposites [1]. Eduard A. Stefanescu and his team conducted research on fiberglass-reinforced polymer composites. They want to investigate the capabilities of these composites as structural dielectrics in multifunctional capacitors. These capacitors necessitate exceptional energy storage capacity and excellent mechanical properties. The search for innovative substitutes for batteries and capacitors, with improvements in performance, weight, and volume, has gained significant attention in recent times. Commercial ceramic capacitors, commonly utilized in applications that demand small sizes, high capacitances, and low insulating resistance, have constraints. They are not appropriate for precise applications because of their extreme sensitivity to temperature changes. Polymer film capacitors are frequently utilized in applications that necessitate low dielectric absorption and loss factors across a broad temperature range. These capacitors have lower capacitances than their ceramic counterparts due to their lower dielectric constants. For high-stiffness, energy-storage capacitors, researchers are building PMMA-fiberglass structural dielectrics with neat or PEDOT: PSS-coated $BaTiO_3$ particles. These versatile capacitors can replace static load-bearing components in traditional structures such as hybrid automobiles or airplanes, leading to a decrease in their total weight and size [2].

Garima Mittal and her team conducted a research study on the production of composites using PMMA, polyimide, and hexagonal boron nitride (HBN) powders. The PMMA matrix contained the powders. The ceramic material known as hexagonal boron nitride (HBN) resembles graphite in its hexagonal lattice structure. It is also known as white graphite and has excellent thermal and chemical resilience, making it ideal for use in high-temperature machinery. For lubrication, boron nitride's hexagonal shape is very well-suited. PMMA/PI polymer composites containing silane functionalized HBN powder show outstanding environmental stability, such as resistance to moisture, UV, and scratches. Consequently, these composites are distinctive. PMMA is a material that possesses excellent mechanical properties, visual clarity, and a low coefficient of friction. Because a charge-transfer complex forms inside the molecules of polyimide (PI), resulting in ordered intermolecular stacking, PI is categorized as a high-performance thermoplastic. PI exhibits exceptional chemical and radiation resistance, favorable electrical properties, and remarkable thermal and mechanical characteristics [3].

Experiments were carried out to assess the mechanical properties of PMMA enhanced with functionalized carbon nanotubes (CNTs) by Leslie Banks-Sills et al. [4]. Carbon nanotube (CNT) is one of the most durable materials known to date, which is an allotrope of carbon, like fullerene, graphite, and diamond. Carbon structures were first alluded to in the 1970s, but only in the early 1990s were CNTs discovered, and their potential understood. Despite having remarkable mechanical, thermal, and electrical qualities, CNTs are usually insufficient when utilized alone. The study will examine the mechanical characteristics of a PMMA matrix reinforced with functionalized CNTs and compare them to the attributes of the same material with un functionalized CNTs. Two distinct methods were used to modify the CNTs. The mechanical properties were also determined to compare the effectiveness of the two functionalization procedures. Tensile tests were used to assess the mechanical properties of the dog-bone test specimens. The composite material was manufactured with a twin-screw extruder, and the specimens were formed using an injection molding (IM) method. In a study conducted by Prashant Jindal et al. [5], analysis was conducted on the mechanical characteristics of PMMA/MWCNT composites subjected to both static and dynamic loads. PMMA is a lightweight polymer frequently

utilized in diverse engineering applications. Its poor mechanical strength hinders its employment, particularly under considerable external static and dynamic loads. To increase the strength of PMMA, it is possible to create and characterize composites using stronger filler materials. One such filler material with special mechanical and structural properties is MWCNTs. The study analyzed variations in the elastic modulus and hardness of different compositions of untreated MWCNTs utilizing nano indentation techniques on PMMA surfaces, without any extra components or surface modifications.

Tetsuya Yamamoto and his team conducted a study [6] Research has shown that recycled carbon fiber fillers from CFRP can improve the mechanical characteristics of adsorbed particle PMMA by being distributed, diffused, and attached to surfaces. Because of their durability and light weight, carbon fiber reinforced polymers, or CFRP, are a common composite material in the space industry. The thermoplastic resin poly (methyl methacrylate) (PMMA) and recycled carbon fibers from grinding carbon fiber reinforced plastics (CFRP) were used to manufacture composite materials. To improve fiber dispersion and increase stickiness, PMMA particles were electrostatically adsorbed onto the surfaces of carbon fibers. This method improved the mechanical characteristics of the composites. In accordance with studies by Chao Shi et al. [7], composites made from surface-modified a-Si3N4 fiber-reinforced PMMA have excellent mechanical properties. This was achieved through free radical polymerization in batches, whereby methacrylate and alkoxy groups were grafted onto hydroxylated Si3N4 fibers and copolymerized with the PMMA monomer via C55C bonds to form g-MPS. The interactions between Si3N4 and PMMA improve the thermal stability of Si3N4-PMMA, increasing its thermal breakdown and glass transition temperature. The aerospace industry and civil engineering could profit from the exceptional mechanical and thermal stability of these composites. After conducting a study on the tensile properties of CNT/PMMA composites, He Runqin et al. [8] determined that the ideal fiber concentration for this specific composite is 20% by volume. Increasing the TiO_2 content enhances the flexural strength of the composite. The presence of TiO_2 improves the attachment of the fibers to the matrix, therefore boosting the flexural properties. An optimal quantity of TiO_2 enhances the impact strength of the 20-vol% CNT/PMMA composite. Adding carbon nanotubes (CNT) and titanium dioxide (TiO_2) has been found to improve the mechanical strength of the composite by augmenting the dispersed phase near the interface.

A research by H. Varela-Rizo et al. [9] evaluated the properties of CNF/PMMA nanocomposites made using three widely used thermoplastic polymer manufacturing techniques. The functionalization of CNF was also taken into account in the study. The potential interactions between the matrix and dispersion were examined in order to evaluate the mechanical properties of the nanocomposites. The covalent bonds in the composites that were polymerized in situ were detected by FTIR analysis, and this was confirmed by other techniques. As a result of dispersion and functionalization, the elastic modulus increased. Melt-compounding did not enhance the modulus, while solvent processing and in situ polymerization did, with a further rise observed when the CNFs were treated. Including CNFs in melt compounding or solvent processing increased the elongation of the material, which in turn improved toughness. Conversely, in the presence of a strong interfacial interaction, like during in situ polymerization, elongation decreased, and the material became stiffer. The samples polymerized in situ, with the inclusion of CNFs, exhibited significant alterations in rheological properties, suggesting that the CNFs expedited the polymer's shift towards a solid-like state. Jialiang Wang et al. successfully demonstrated a method for chemically bonding PMMA to graphene oxide sheets [10]. Graphite was exfoliated to form graphene platelets in N-methyl-2-pyrrolidone (NMP) and subsequently polymerized in a solution containing well-dispersed graphene platelets. The PMMA modified graphene Nano platelets were analyzed using several methods, revealing that the GPMMA created possessed a flawless structure, which enhances its suitability for strengthening composite materials GPMMA's excellent dispersion in organic solvents facilitates the production of many composites. The PMMA/GPMMA composite film exhibits a substantial enhancement in mechanical properties, with Young's modulus and tensile strength increasing by 151% and 115%, respectively, compared to the pure PMMA film, with

only 0.5 wt% GPMMA incorporated. Additionally, the robust interfacial adhesion and good dispersion in the PMMA matrix enhance thermal stability.

Jun-long CTC-IPN technology can change the CE, according to studies by Wang et al. [11]. When compared to pure cellulose ether, modified cellulose ether has better mechanical qualities. The mechanical properties peaked when the CE/PMMA weight ratio balanced at 80/20. When compared to pure CE, the flexural strength increased 1.31 times and the impact strength increased 2.37 times. Silicon dioxide can increase the polymer's weight-bearing capability. In comparison to its mechanical qualities without the addition, the impact and flexural strength of IPN rose by 20.05% and 29.96%, respectively, when nanoscale SiO2 was added to the material. In the sliding tests, increasing the applied loads, sliding speeds, and ZrO2 filler content increased the coefficient of friction for both pure PMMA and ZrO2-filled PMMA composites, per the study of A. Akinci et al. [12]. Wear rates decrease when the PMMA composite's ZrO2 concentration rises to 30%wt, as well as when applied loads and sliding speeds increase. The wear rate of the PMMA + ZrO2 composite decreased as the ZrO2 component increased. The worn surfaces of PMMA composites filled with ZrO2 showed smooth morphologies with minimal abrasive grooves for both the 10% and 30% ZrO2 compositions. As the ZrO2 content increases, the surface becomes smoother.

The study conducted by Poomalai et al. [13] the blends' tensile strength and tensile modulus somewhat decreased as the TPU content increased, while the percentage of elongation at the fracture site noticeably increased. Pure PMMA has low wear volume loss, whereas the 80/20 PMMA/TPU blend has the highest wear volume. There is a more robust relationship between certain mechanical factors and wear volume in both pure PMMA and a 95/5 PMMA/TPU blend. While TPU exhibits superior wear resistance, the addition of PMMA to this polymer does not enhance its abrasion resistance. The abrasion process led to the formation of extensive grooves, wider cracks, and an increased number of particles, as observed in scanning electron microscope (SEM) images of blends including thermoplastic polyurethane (TPU) filled with poly methyl methacrylate (PMMA). Vasudeva Rao and colleagues studied the abrasion behavior of aluminum metal matrix composites (MMC) reinforced with h-BN and c-BN. Their Journal of Nanomaterials study illuminates these composites' wear properties. In Advances in Materials Science and Engineering, A. Bovas H. Bejaxhin and colleagues examined the tribological and surface roughness features of CNC-milled dual heat-treated Al6061 composites. Y. Brucely et al. studied online acoustic emission measurements for AA8011-TiC-ZrB2 hybrid composites, and C. B. Priya et al. optimized wear studies on Mg-5Sn-3Zn-1Mn-xSi alloy using the Integrated RSM-GRGA technique in Silicon. This research illuminates high-performance composite material wear and surface qualities, providing useful recommendations for many industrial applications. Reviews various aspects and concludes of PMMA bio materials composites was suitable for dental applications. PMMA's enhanced qualities include its low density, attractiveness, affordability, ease of use, and customizable mechanical and physical attributes [12, 13]. According to studies, bacterial growth and biofilm development are always troubling because of the associated infection-related illnesses and the financial strain on the healthcare system. [14] Bacterial adhesion and plaque in the oral cavity are linked to a number of common disorders, such as dental caries (tooth decay), periodontal diseases, and denture-induced stomatitis, which leads to fungus development. [15] Surface functionalization and the addition of bio-components such antimicrobial polymers, inorganic nanoparticles, or medications, showing encouraging results against a range of oral microbes. The bulk of research has been done in vitro, despite the fact that the inclusion of antimicrobial nanoparticles has not caused any problems with biocompatibility. In a complex, dynamic oral environment, a material's reactions, including its antimicrobial activity, may vary. A variety of antibacterial compounds have the potential to cause cytotoxicity. Thus, more in vivo clinical research is necessary to confirm the antimicrobial drugs' effectiveness as well as their biosafety and biocompatibility. [16]

The inclusion of some nanoparticles has been shown in experiments to either affect aesthetics (color, translucency) or cause biocompatibility problems by causing degradation products to seep into the

mouth cavity. Consequently, further research ought to be done in this area. There are situations when the nanocomposites' biocompatibility is dubious and needs more research. [17] Materials in the mouth are more likely to become complex, including a variety of endogenous (polysaccharides, bacteria, proteins, and enzymes) and exogenous (components derived from a diet high in dairy) substances. In a typical biodegradation process towards the biomaterials in the oral cavity, these components create complex interactions that lead to a considerable mechanical activity. These procedures could alter the properties of the material and compromise its functionality. [18] that a biomaterial's biodegradation may produce leachable molecules that set off a series of biological events in organisms and tissues. Although there is disagreement about how biodegradation affects the biocompatibility of acrylic materials, as empirical and subjective complaints about these materials rise, concerns about their potential clinical ramifications are emerging Polymeric materials have historically been described as large, stable structures with exceptional biodegradability, according to [19]. Numerous studies have revealed that polymers in the oral cavity may be vulnerable to a range of biodegradation processes. Numerous factors, such as changes in pH and temperature, salivary enzymes, dietary and chemical changes, and chewing, promote the biodegradation of polymers [20–23]. The number of printed layers, the shrinkage that occurs between the printed layers, the laser's speed, intensity, angle, and building direction, the type of software used, the restoration's position and angle on the printing platform, the amount of supporting material, and post-processing techniques are all crucial factors in achieving predictable, successful, and accurate interim 3D prosthetic restorations, in addition to a proper chemical composition that ensures good oral biocompatibility. [24] It is well known that differences in printing parameters and technical printing procedures have been observed. Additionally, because manufacturers have not yet fully disclosed the chemical compositions of the 3D printed materials, comparing the findings of the various studies that are currently available may be particularly difficult [25–26].

From the literature review it is observed that requirement for replacement as PMMA biomaterial and study their material characteristics. In this research article, PMMA is taken for the analysis of the replacement of biomaterial particularly for hip joints. In this concern material properties of PMMA are investigated by tensile test, impact test, flexural test, and DMA test. The outcome of the result shows better ductility properties with high tangential and loss modules. The research also looks at the biocompatibility of PAAM by analyzing the material with bio-toxic tests which also reveals better bio implants characteristics.

MATERIALS AND METHOD

When qualities like tensile strength, flexural strength, transparency, polishability, and UV tolerance are more crucial than impact strength, chemical resistance, and heat resistance, PMMA is a more affordable option than polycarbonate (PC). Furthermore, PMMA is devoid of the potentially hazardous bisphenol-A subunits that are present in polycarbonate. It is frequently favored due to its moderate characteristics, convenient manipulation and treatment, and affordable price. Unaltered PMMA exhibits brittle behavior when subjected to a load, particularly under an impact force, and is more susceptible to scratching compared to traditional inorganic glass. Modified PMMA can achieve notable scratch and impact resistance. Due to the superior qualities of PMMA compared to other polymers, this study has selected Silicon Carbide as one of the materials for the fabrication of composites. In our Research work, PMMA Granvals are taken as material which is purchase from Srivnasa polymers ltd Chennai. The size of the granvals approximately 10mm3 cubic in shape. the PMMA cleaned with distilled water and it is mixed with Epoxy Resin (HY553) with the ratio of 1:10 weight percentage. The PMMA Mould Process shown in Figure 1–3.

The mold will replicate the product's shape. To get a glossy or textured finish on the product, the mold surface must likewise have the corresponding finish. If a smooth outside surface is desired for the product, it is manufactured inside a female mold. If a smooth inner surface is required, the molding process is carried out using a male mold. The mold must be defect-free to prevent any imperfections from transferring onto the product.

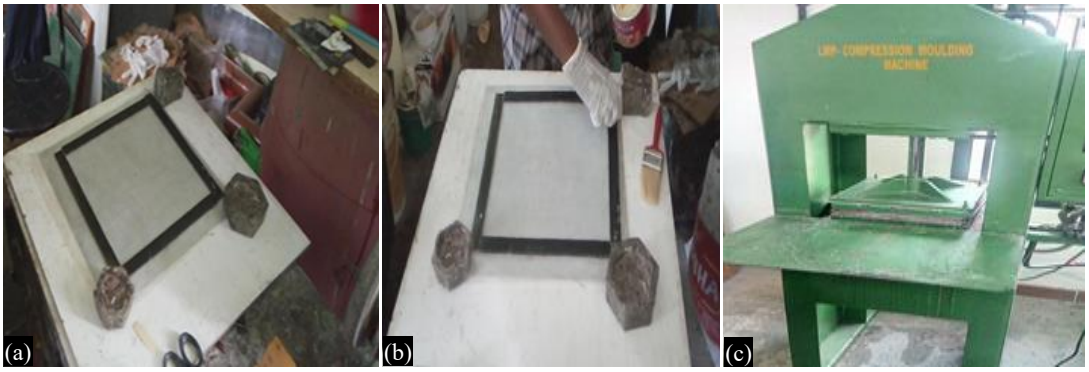


Figure 1. (a) Hand lay method of deposition; (b) Mold set up; (c) Press with die assembly.

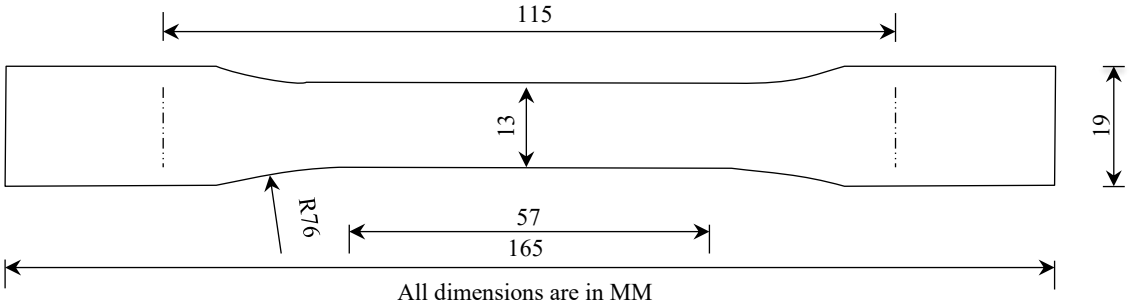


Figure 2. Tensile tested sample.

Figure 3. Tensile test specimen.

Film or layer: The product may stick to the mold because of the strong adhesive characteristics of the resins used. An adequate release mechanism should be incorporated. Applying a release layer of either wax or polyvinyl alcohol (PVA) might alter the product release. Using a thin material like polyester film (Mylar). Because the Mylar sheet needs to match the mold profile, this method is not appropriate for complex shapes. The prepared mold is placed in the bottom part of the compression press, the upward raw is moved down with 20kN applied load gradually at temperatures of 130 degrees Celsius under atmospheric pressure for 20 minutes with a cooling time of 30 minutes. The molded plate is taken from the die which is processed with water jet machining (EMA 10) to study the machining characteristics such as tensile strength, bending, flexural, wear, DMA and Bio toxic.

Tensile test

The tensile strength has been carried out as per the ASTM D638-03 standards as exhibited in the Figure 4. The sample was prepared by water jet machining from molded plate for a sample of 3. The sample was cleaned by using a stone liquid for before testing. the testing sample was shown in Figure 4. The tensile test was conducted in ZESIS UTM Machine with minimum load of 10N in uniaxial direction. The tested valves are listed in table.

Flexural test

The sample (Figure 5) for the Flexural test is prepared as per the ASTM D270 standards using water jet machining from the molded plate for a sample of 3 which is 12.7mm in width, 100mm in length, and thickness of 4mm shown in Figure 7. The test is carried by cantilever type of arrangement in which one end is fixed with rigid joint and other is free to apply a load of 10N at 90mm length from the fixed end. The uniformly deflection and strength due to point load is listed in tested.

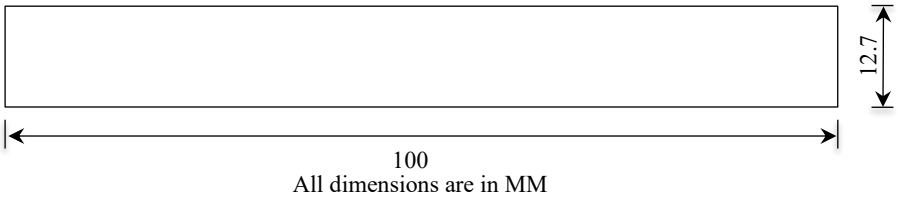


Figure 4. Flexural tested sample.

Figure 5. Flexural test specimen.

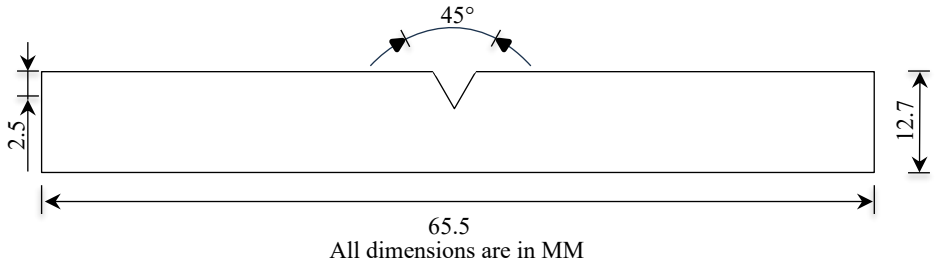


Figure 6. Impact test specimen.

Charpy Impact Test

The ASTMD256 (Figure 6) standard is used for preparing Charpy impact test samples with dimensions of 65.5mm length, 12.7mm width, and 4mm thickness. A V-groove is made at the center, as depicted in Figure 10. The test was conducted using a specially constructed impact machine that is calibrated with an NABL-certified instrument. The samples were positioned horizontally and then subjected to impact loading using a hammer setup. The tested values are shown in table.

Analysis of Dynamic Mechanics

In Dynamic Mechanical Analysis (DMA), a technique for material characterization and product research, especially for investigating the viscoelastic characteristics of polymers, a material is subjected to a sinusoidal load, and the strain that results is monitored in order to calculate the material's complex modulus. In a specific experiment, a specimen measuring 50 mm in length, 4 mm in thickness, and 10 mm in width underwent two-point bending testing and achieved a maximum of 1000 mF. The experiment was carried out at 200°C, with heating rates ranging from 0.2 to 10 degrees per second. Figure 7 depicts the setup utilized for DMA analysis.

Figure 7. DMA setup.

RESULT AND DISCUSSION

Tensile Testing

The graph Figure 8 shows Solid fracture can be viewed as the production of new surfaces in the medium in a thermodynamically irreversible manner.

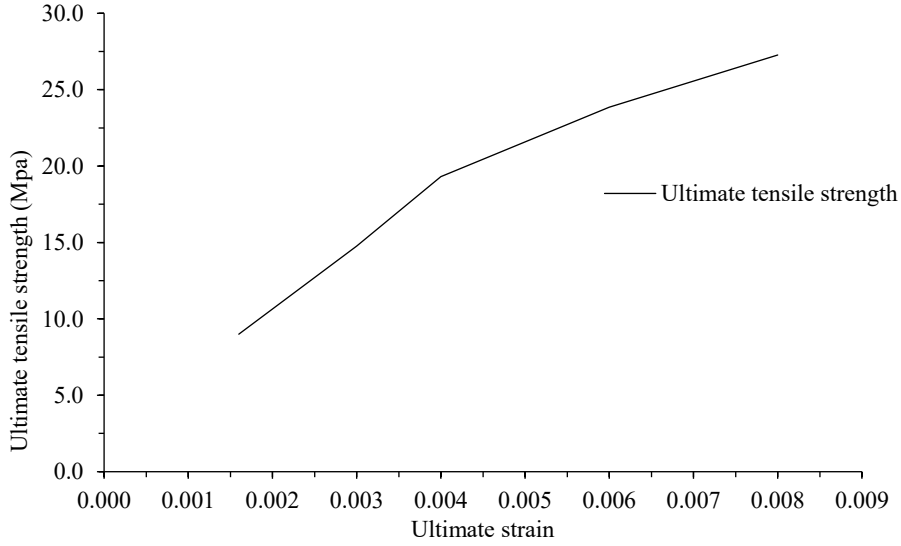


Figure 8. Tensile test graphical result.

The breaking down of cohesive bonds within the material is the fundamental characteristic of the process. In simple terms, the fracture is a process of nucleation, growth, and/or coalescence of voids or fractures. Although the intricacies of this process may vary depending on the material, the type of external forcing, and the climatic conditions, generally speaking from the macroscopic standpoint, one can describe the fracture of solids in two broad categories, namely brittle and ductile. Large deformations, extremely high rates of energy dissipation, and sluggish fracture velocities are typically linked to ductile fractures. Brittle fracture is a low-energy failure that typically occurs catastrophically under unstable loading conditions, resulting in high fracture velocities. Based on the crack growth

theory mentioned above, it can be noted that internal crystal structure dislocation and intergranular dislocation cause fracture formation, leading to the production of voids. Thus, the index of fracture propagation will be generated. Crack propagation will accelerate as the load duration increases. As a result, when the cracks expand, the material will fail. In this situation, the maximum tensile strength was computed. According to the main theory of the crack initiation process, the SEM images (Figure 10) were shown in internal exothermic mode. The observed test results from the graphs and table indicate that biomaterials have tensile characteristics. At least 5 PMMA samples were tested to measure their material characteristics. The maximum tensile strength was 42MPA, shown in Table 1 and the maximum impact strength was 3. 87j.shown in Table 2. The material exhibited improved ductile qualities due to increasing tensile strength and decreasing impact strength. Hence the material has high tensile strength which leads to use in a biomaterial application.

Flexural Testing

This graph (Figure 9) and Table 3 depicts the flexural pictures which are shown in tabular format. In the flexural test, one end is fastened and the other is loose. In this test arrangement, the material initially resists the bending moment. The granules are displaced as a result of applied stress. As a result, the material will experience shear forces. The shear force will gradually grow, leading the material to break in either flexural or shear modes. The ultimate flexural stress will be computed by measuring the flexural valve's or shear valve's end. The product was shown under the highest flexural stress, and the material will elongate. As a result, the material's failure mode will be ductile. The SEM image (Figure 10) also shows the ductile failure characteristic. Thus, the substance will be used as a bio implant material. The flexural strength (1) was calculated below the formula

Flexural stress = Force/breath of the sample* Thickness (1)

Table 1. Tensile test result.

S.N.	Ultimate tensile strain	Ultimate tensile stress in Mpa
1	0.0016	9
2	0.003	14.77
3	0.004	19.31
4	0.006	23.86
5	0.008	27.27

Table 2. Impact test results.

S.N.	Impact load load	Impact strength in j
1	10	5
2	15	4
3	20	2
4	25	3
5	30	5

Table 3. Flexural test results.

S.N.	Ultimate flextural strain	Flextural stress in MPA
1	0.028	3.92
2	0.035	3.29
3	0.042	3.29
4	0.049	3.17
5	0.056	2.88

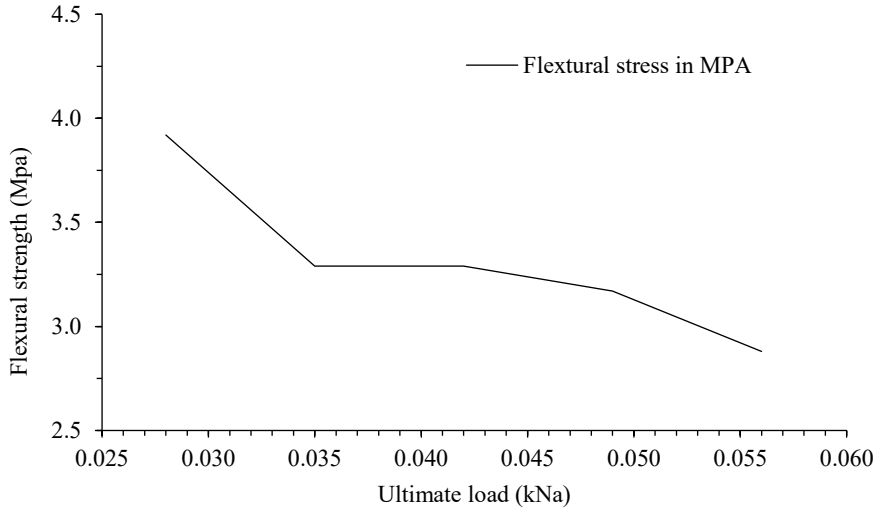


Figure 9. Flexural test graphical results.

SEM Image of PMMA

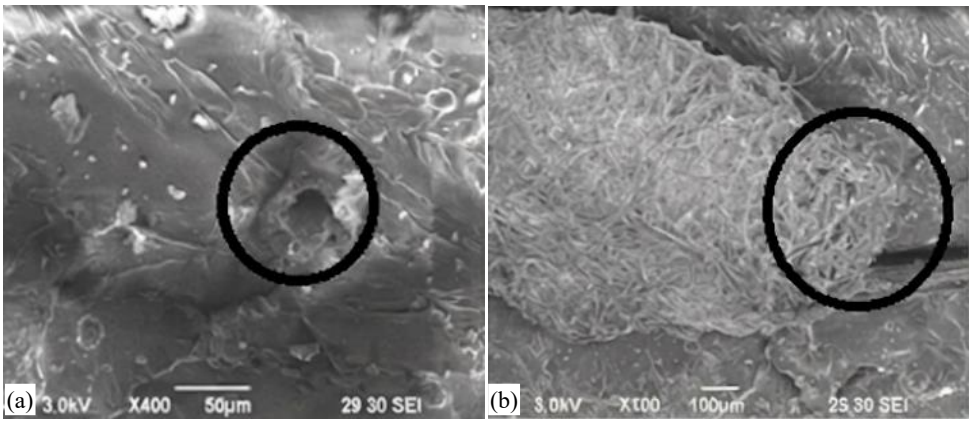
Scanning Electron Microscope Analysis (SEM)

The study of material characterization is essential for investigating the morphology of a material, which may be achieved through the utilization of a scanning electron microscope. Evaluating the uniformity of the reinforcement inside the matrix material is the aim of this investigation. SEM analysis using the ZEISS equipment was carried out on several fiber sample fracture surfaces at magnifications ranging from 20X to 500X. The fiber-reinforced composite was subjected to fractography because of its exceptional mechanical properties. The composite material's failure in mechanical testing was discovered using SEM analysis; the picture of the fractured surface is shown in Figure 10. In Figure 10 (a), the SEM image shows the fracture surface of the composite reinforced with fiber under tension. Fractography revealed that some fibers were pulled out while others were broken, indicating high interfacial bonding within the composite. Additionally, the fractography displayed cavities and delamination, pointing to poor matrix-reinforcement adhesion. The composite material is mainly fractured through fiber pull-out and fiber fracture.

The SEM image was shown in different magnifications. The SEM image was taken in ZESSIS Equipment. In the SEM image figures10 A and 10 B Tensile fracture were shown in a Tensile fracture of the SEM. The SEM was taken in 100x and 400X magnification. The SEM image was shown in an internal heat generation. The internal heat generation happened due to external loading condition. And figure 10b Tensile fracture was shown in a tensile fracture. The tensile fracture occurred a due to a tensile loading condition. The SEM image was shown in a fiber as enlargement condition so the material was given in a ductility property.

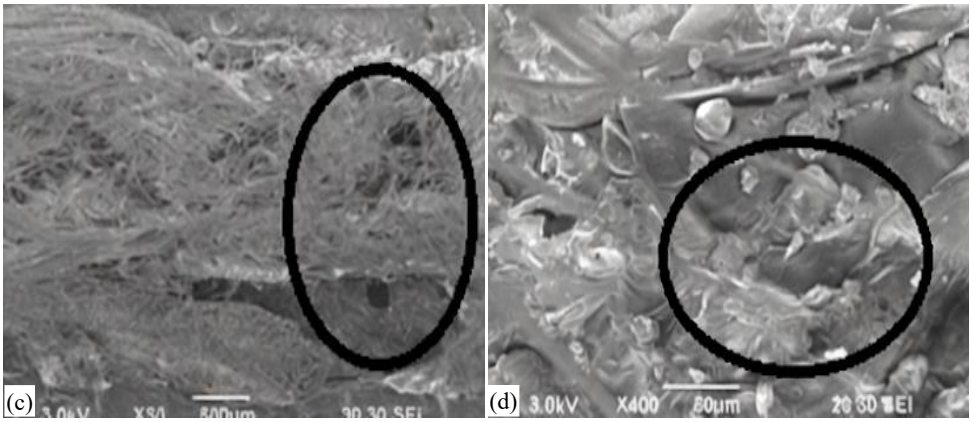
Figures 10(c) and 10(d) Flexural Fracture was shown in a Flextural Fracture of the material. The Flexural Fracture was taken in a 40 and 400 X magnification. The figure 10E impact fracture was shown in an internal void. The internal voids were happening in a due to internal gas formation of the molding constitution. And figure 10F Impact fracture was shown in an internal crack formation due to Flexural loading. The internal crack growth was shown in a ductile fracture.

Figure 10(e) and 10(f) Impact fracture Was shown in a Toughness Fracture of the material. The Fracture image was taken in a 250 and 500 X magnification. The image was shown in an internal crack formation was happen due to sudden loading condition. And the image 10 (f) was shown in a toughness shear of the material. The toughness condition material will be enlargement. The sample was shown in ductility properties. Finally, the fracture surface of the material was shown in ductility properties.



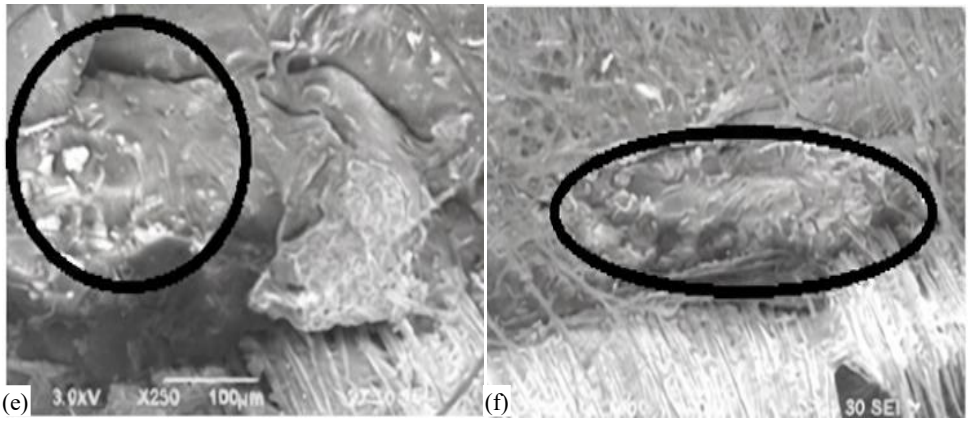
Hexothermic heat generation formation due to internal heat generation

Fiber enlargement due to tensile loading



Internal void occurred

Internal cracks due to shear loading



Internal crack generation due to toughness loading

Impact shear due to toughness loading

Figure 10. SEM micrographs of PMMA polymer biomaterials. (a) Tensile Fracture; (b) Tensile Fracture; (c) Flexural Fracture; (d) Flexural Fracture; (e) Impact Fracture; (f) Impact Fracture

Hence material was performed high loading condition. Hence the material will be preferred for bio material application.

XRD Results

The XRD Results (Figure 11) is generated using origin graph. The graph is obtained from two separate theta valves. In general, two theta valves were explained in terms of crystal structure lattices.

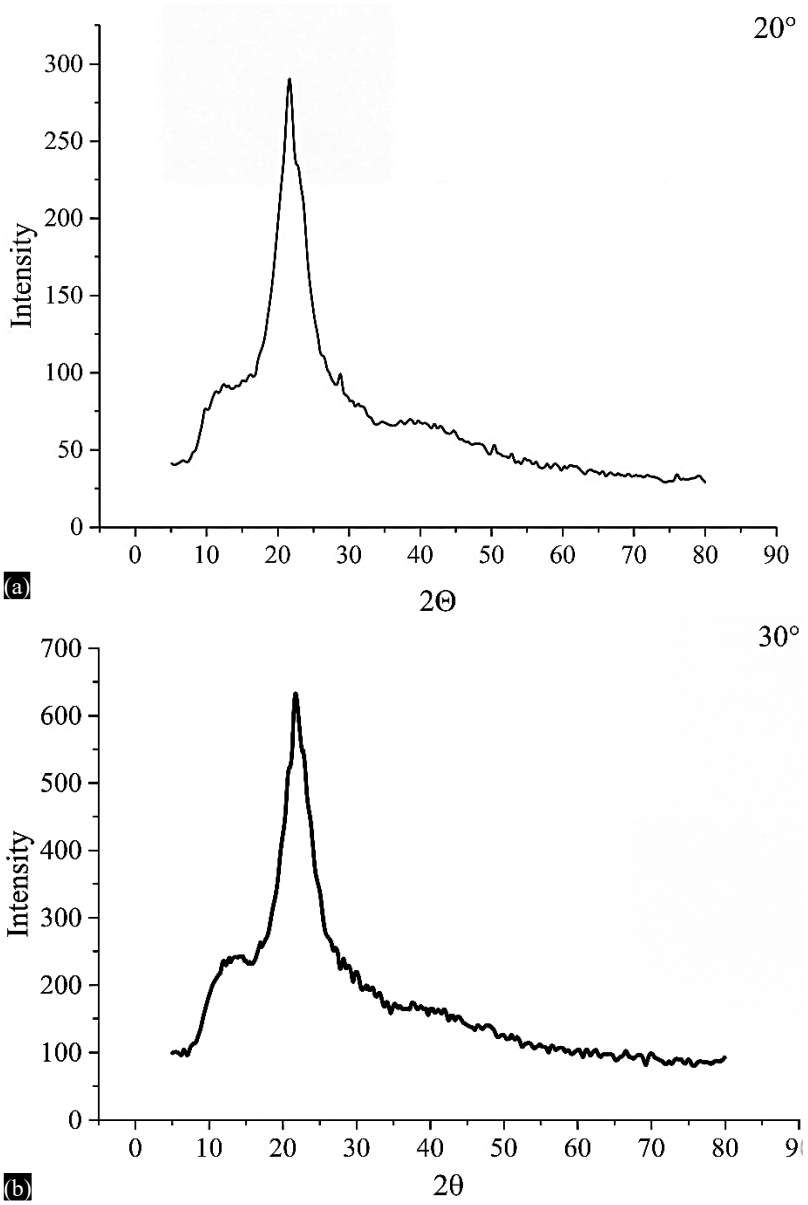


Figure 11. XRD RESULTS for 2theta analysis. (a) XRD at 20 degree; (b) XRD at 30 degree.

The graph shows that the lattice parameter was 20 degrees and 30 degrees which shows separate peak valves. The peak valve was associated with a material feature. The 20-degree maximum peak intensity valve was seen in a 280 cubic meter. As a result, the corresponding material qualities were noticed in the JCPDS charts, it has a homogeneous structure and produces excellent ductility. The corresponding impact strength was also shown as 5 joules. The valves are matched using a JCPDS chart. So, the XRD results were analyzed using a JCPDS chart and experimental valves. This material has exhibited high shear and toughness. So the substance will be used in a bio application.

DMA Result

The Dynamic Mechanical Analysis Result shown in graph Figure 12. The graph an explained temperature vs. loss modulus. The second graph b was explained in a time vs loss modulus. The graph explained the temperature keep on increased the loss modulus will be decreased. The reason of the mechanical and material point of view is when the temperature keeps on increasing the material crystal structure will be varied. Hence the material will be loss the strength. The final result is material will be

fractured. Here the material maximum temperature was obtained in 135 degree Celsius. And the maximum tangential modulus is 2 e10. And corresponding the time vs. tangential modulus graph was explained in the vibration factor increase on time. When the vibration valve increased same crystalline structural will be varied. Hence the material will be meeting on fracture surface. The maximum time withstand in a material is 30minutes and maximum loss modulus will be 2e10. Hence the result was proved that the maximum young's modulus will be obtain form both temperature and time is 2e10. Hence the material will be proved that the dynamic result as maximum loss modulus 2e10 and 35minute and 135 degree will be withstand in a material.

BIO TOXIC TEST RESULTS

The National Centre for Cell Sciences (NCCS) in Pune, India, provided the human monocytic leukemia cells THP-1. The cells were grown in RPMI 1640 medium with 20% inactivated Fetal Bovine Serum (FBS), Penicillin (100 IU/ml), Streptomycin (100 mg/ml), and Amphotericin B (5 mg/ml) under 5% CO2 at 37˚C until they formed a complete.

Determination of Cell Viability

Dialysis membranes were assessed on THP-1 cell lines to test cell viability by PI staining and flow cytometry (FACS) with the BD FACS Caliber equipment, following the method outlined by Vinnee et al. in 2018. THP-1 cells were cultured at a concentration of 20,000 cells/ml with biomaterials for 18 hours.

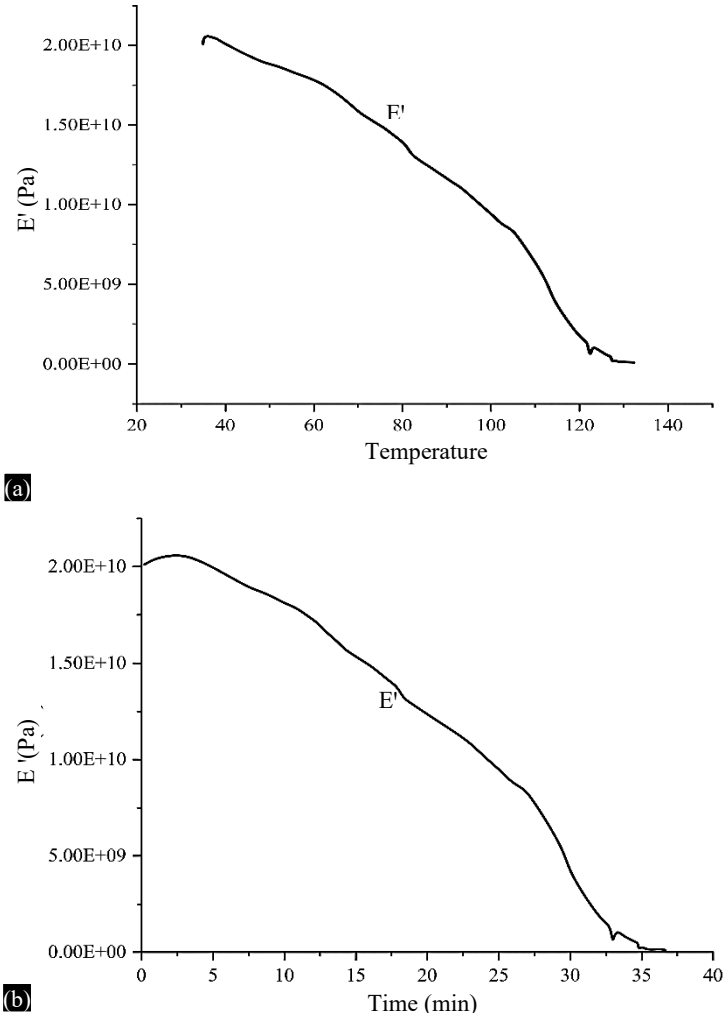


Figure12. (a) and (b) Dynamic mechanical loss modulus.

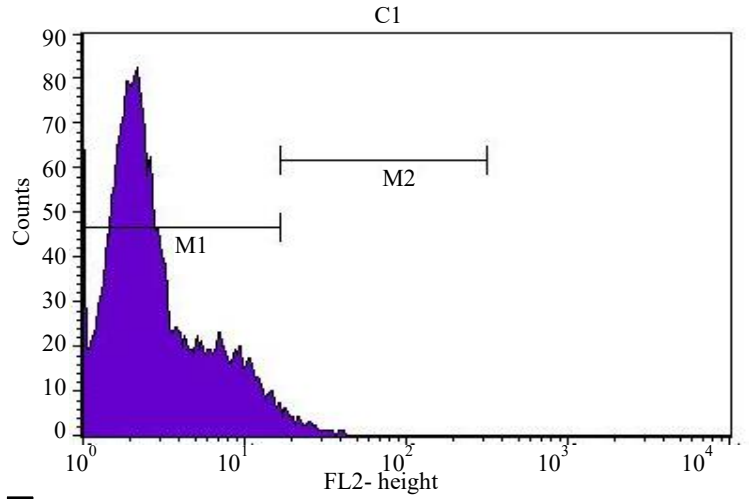
Table 4. Observations of live cells and dead cells percentages

Samples	% Live cells	% Dead cells
C1 -Untreated Control cells	97.87	2.13
PI CRL 1 -Positive Control Cells	56.52	28.37
PI PC 1 -PC	94.93	5.03
PI PMMA 1 -PMMA	95.03	4.97
PI PP 1 – PP	96.59	3.35

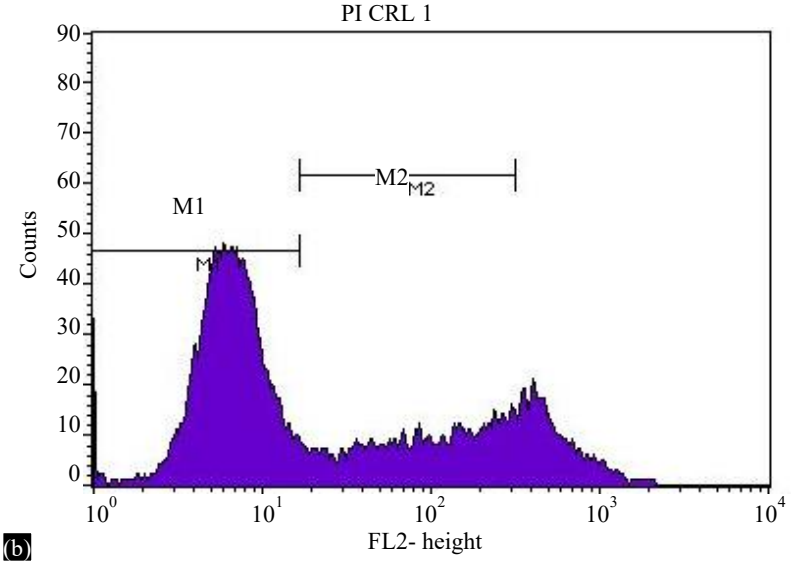
Following incubation, the cells were centrifuged, formed into a pellet, suspended in FACS buffer, and stained with 10µl of 1mg/ml propidium iodide (PI) for 10 minutes in the dark. Cell viability was assessed using FACS with the FL2 detector and analyzed using BD CELLQUESTPRO.

The enclosed Table 4 illustrates live and dead cell percentages for cell research samples. A control group of untreated cells (C1) and a positive control group with PI production by CRL 1 (PI PC 1) and a group of treated cells with a different material (PI PP 1, PI PCMMA 1) are included. Dead and live cell proportions of each sample are indicated on display. The healthy and viable population of live cells was shown to be 97.87% and dead cells constituted 2.13% in the untreated control cells (C1). PI CRISPR-Cas9 control cells (PI CRL 1) have less number of living cells (56.52%) and dead cells (28.37%). This negative control construct is a marker for cell viability. Permeable interretor PI staining was done to PI PC 1, PI PMMA 1 and PI PP 1 treated cells and different live/dead ratios were calculated. The percentage in cell survival ranges from 94.93% to 96.59 in all cases. Dead cell percentages were recorded as 3.35% to 5.03%. The treatments influence cell viability, as it has been shown by the varying live cell and dead cell percentages. The findings inform of toxicity (cytotoxicity) or biocompatibility of the materials, and it indicates their possible applications in cells' uses. The variation in the cell viability is done to see the comparison of each substance to the cellular health and the study can go deeper to future studies and application.

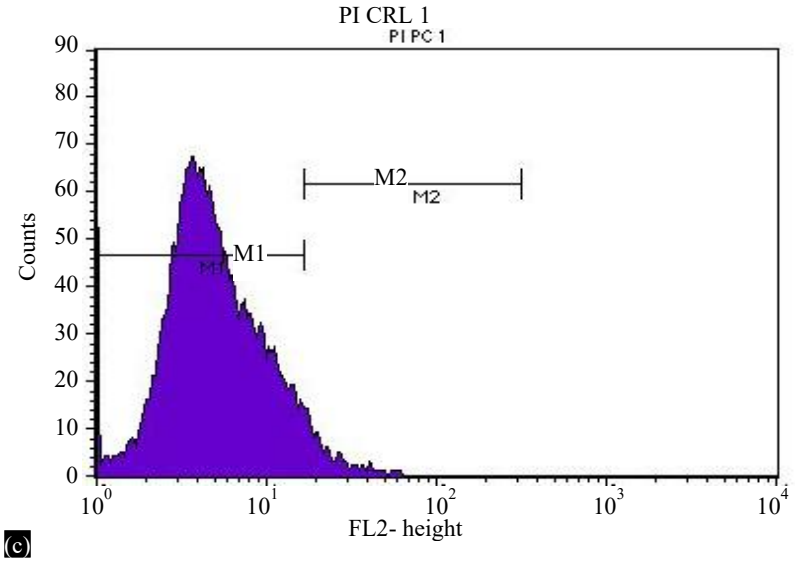
Angle 5 displays the bio-toxicity levels of different polymer composites, particularly PI PC 1, PI PMMA 1, and PI PP 1. The measured levels of bio-toxicity can ideally be predicted based on cellular responses that were observed in previous experiments. The different materials and properties of these polymer composites will give quite varying results on cellular viability. The Figure 13 graph can be used as a clear compared representation of the bio-toxicity profiles of the materials hence identifying the trends and differences in how they interact with living cells. The knowledge of the types of proteins that adsorb to the implant material's surface can be of great use in the field by the researchers and the practitioners alike.



(a)



(b)



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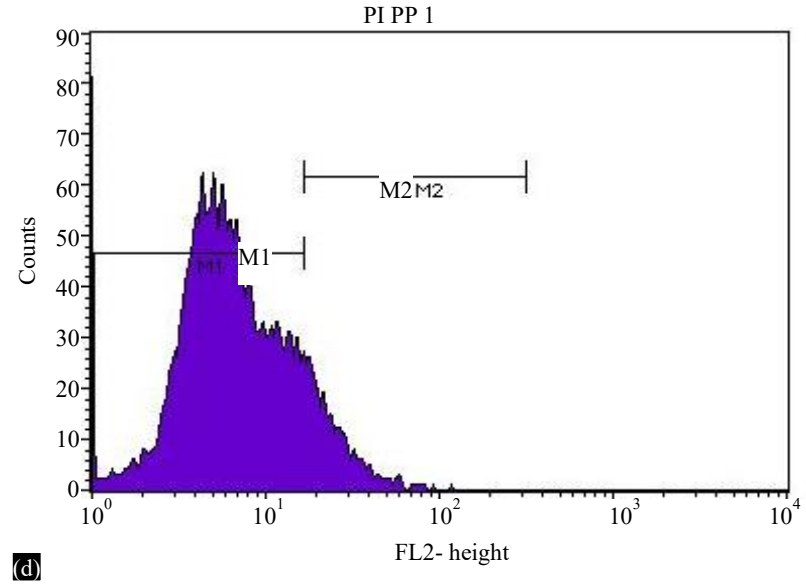

(d)

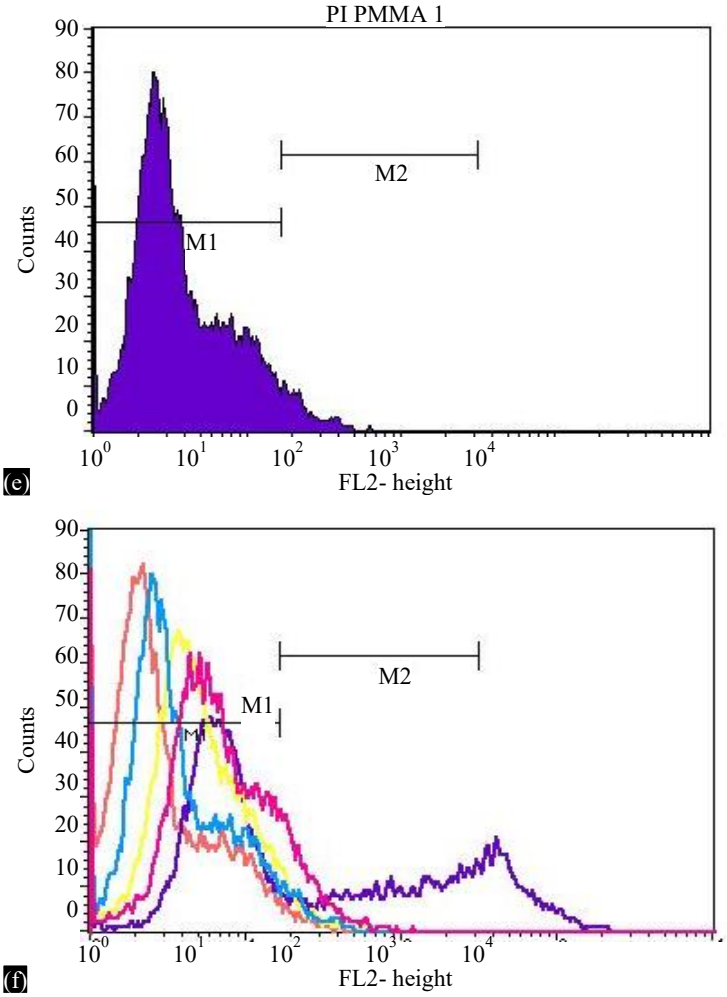

Figure 13. Bio toxicity levels of different polymer composite.

It enables them to choose the most biocompatible materials for the application. Hence, it would facilitate the creation of artificial living structures and biomaterials. The figure illustrates in a visual way the bio-toxicity evaluation and therefore assists a quick and knowledgeable grasp of the relative safety of the polymer composites under consideration.

CONCLUSIONS

In this research compressive mold manufactured PMMA material is taken for the investigation for the application of bio implants particularly for hip joint replacement. The material characteristics of PMMA are analyzed using tensile, flexural, bending, and impact tests. The Fracture surface characteristics are also investigated using SEM images. In addition, bio toxicity is also analyzed to find the PMMA biocompatibility. The findings of the research are listed below:

- The maximum tensile test observed is an average of 42Mpa, the corresponding fracture image shows fiber enlargement.
- The flexural result shows 66.3Mpa in which the corresponding fracture surface infers better fiber enlargement.
- The maximum impact is 3.87Joule and the fiber fracture has fiber enlargement,
- Hence all the mechanical tests show a fiber enlargement nature which reveals better mechanical characteristics with ductile material properties. This confirms that material can be used in biomaterial applications.

- In dynamic mechanical analysis, the loss modulus decreased with increasing temperature and time due to changes in crystallographic properties. The maximum temperature obtained is 136 degrees Celsius at 36 minutes. Hence DMA results show better crystal stability of material.
- In addition, FEM analysis is used to identify the maximum stress distribution by using ANSYS 12 workbench software. The results show a stress value of 31.7N and displacement of 0.401mm this conforms to the PMMA materials used in bio implant products.
- The biomaterials examined did not provide substantial cytotoxicity against THP-1 human leukemia cells. Biocompatible materials were mentioned. Table 4 summarizes cellular response to treatment and material. High percentages of live cells in the alive control cells (C1) indicate a healthy and viable cell population. PI-CRL-1 was a control for positive cells with fewer live cells and more dead cells. We found that PI PAAM, P2 PMMA1, and P3 PMMA affect cell viability differently. Despite the differences between samples, the population had a high percentage of viable cells (94.93% and 96.59%). The experiment recorded 3.35–5.03% dead cells. This shows that the investigated materials (PI PAAM, P2 PMMA1, and P3 PMMA) are biocompatible since they can support cell viability. The variable cell viability in the treated samples has to be further investigated to determine how each material affects cellular health.
- Future studies will include analyzing virology testing, cell growth testing, and other bio-characteristics tests, as well as incorporating them with medical practitioners to validate biomaterials.

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