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EXPERIMENTAL INVESTIGATION OF MECHANICAL PROPERTIES OF 3D PRINTED PLA/TPU/CAPRA HIRCUS POWDER COMPOSITES

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ABSTRACT:
The integration of natural fillers into polymer matrices has garnered significant interest in the development of sustainable and bio-based composites. This study explores the preparation and utilization of CAPRA HIRCUS (goat) bone powder, processed without heat treatment, as a filler in a polymer blend of Poly(lactic acid) (PLA) and thermoplastic polyurethane (TPU). The Capra hircus bone powder was prepared by grinding and sieving to achieve a fine particle size suitable for blending. The PLA, TPU, and Capra hircus bone powder were mixed in specified ratio and extruded into filaments using a filament extruder. These filaments were then utilized in fused deposition modeling (FDM) 3D printing to fabricate tensile, compression, and flexural test specimens according to ASTM standards. This work highlights the challenges and opportunities associated with incorporating natural fillers into polymer matrices, emphasizing the need for optimization in material formulation and processing to achieve balanced mechanical and environmental benefits. Future studies will focus on improving filler dispersion and interfacial compatibility to enhance the mechanical properties of such bio-based composites.
Keywords:PLA, TPU, capra hircus bone powder preparation, filament extrusion, 3d printing, mechanical testing.

INTRODUCTION:
Biopolymers are a type of polymer produced from renewable resources, made up of plants, microorganisms, and agricultural waste. In recent times, biopolymers have attracted considerable attention as a more sustainable and eco-friendly alternative to conventional plastics derived from petroleum. Two commonly used biopolymers are PLA (Polylactic Acid) and TPU (Thermoplastic Polyurethane)[3]. Blending these two biopolymers and CAPRA HIRCUS (Goat) bone powder) offers a range of advantages and unique properties for biomedical applications. These interacting combination of PLA, TPU, and goat bone powder aims to produce a composite material that influence the biodegradability and processability of PLA, the flexibility and toughness of TPU, and the bioactivity of goat bone powder[2][4]. The primary component (PLA) acts as the biopolymer matrix, while goat bone powder serves as a reinforcement, contributing to the material’s eco-friendly and bioactive characteristics[1].
Goat bone, with its mineral richness and bioactivity, enhances the mechanical and biological properties of composites when blended with polymers PLA & TPU[9]. CAPRA HIRCUS (Goat) bone contains rich in hydroxyapatite[5][6]. So, it ensure the hydroxyapatite applications[8]. These composites in Bone scaffolds, implants and Fillers in dental cements, contributing to both advanced material science and eco-friendly practices[10]. These composites can be used to create scaffolds that

support bone regeneration, providing both mechanical support and a helpful environment for cell growth[7].The enhanced mechanical properties and biocompatibility make these composites suitable for evolving implants that can integrate with bone tissue and degrade safely over time[12].

EXPERIMENTAL WORK:

PREPARATION FOR CAPRA HIRCUS BONE POWDER:

Capra hircus (goat) bones were collected after removing the meat. Cleaned again using a knife to remove excess meat and fat as shown in figure 1.The goat bone was then boiled in NaCl + water at 80°C for 150 min. After boiling, fats, meat and debris are removed. After cleaning, the bones were Dried at room temperature (~30°C) for 72 hrs as shown in figure 2. Bones were Broken manually using a hammer as shown in figure 3. The dry broken bones Were crushed using a rolling crusher as shown in figure 4. The crushed granules are milled to the desired size using a ball milling machine in 90 minutes as shown in Figure 5. Then the powdered goat bone was sieved through a 100 μm sieve as shown in figure 6. Goat bone powder was processed without heat treatment to Stabilize the organic matter and minerals in the whole product.

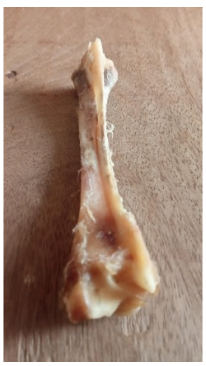

Figure 1 Cleaned Bone Figure 2 Cleaned Boil Bones Figure 3 Dry Broken Bones



Figure 4 Roll Crusher Figure 5 Ball Milling Figure 6 Powdered capra hircus bone

SELECTION OF MATERIALS:

PLA (Poly(lactic Acid)) :

Figure7 PLA pellets

Both PLA and TPU are biodegradable polymers derived from renewable resources, making them environmentally friendly choices for 3D printing. PLA is a biodegradable and bioactive thermoplastic derived from renewable resources like corn starch or sugarcane as shown in figure 7. PLA offers numerous benefits, especially in terms of environmental sustainability and ease of processing. Its biodegradability, renewability, and suitable mechanical properties make it an attractive alternative to traditional plastics for a wide range of applications. Virgin PLA get more brittleness during the filament extrusion process.

TPU (Thermoplastic Polyurethane):

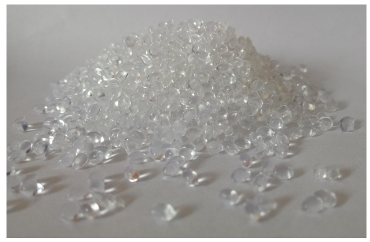

Figure 8 TPU pellets

TPU can be synthesized from bio-based polyols, contributing to a reduction in dependency on fossil fuels as shown in figure 8. TPUs biodegradability, derived from bio-based sources (like vegetable oils or other renewable materials) along with its excellent mechanical and processing properties, make it an attractive choice for various applications. TPU (Shore hardness – 65A) is known for its excellent elasticity, flexibility, and resilience, making it ideal for applications that require materials to stretch and recover their shape.

CAPRA HIRCUS (Goat) Bone Powder:

Figure 9 capra hircus bone powder

CAPRA HIRCUS (Goat) bone is derived from a natural source, making it a easy to available, renewable and sustainable material as shown in figure 9. Goat bone, with its mineral richness (Hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$), magnesium, potassium, sodium and strontium) and bioactivity (Goat bones are made up of 9.19% moisture, 49.43% ash, 10.10% fat, and 22.12% crude protein), enhances the mechanical and biological properties of composites when blended with polymers PLA & TPU. CAPRA HIRCUS bone powder can provide an economical alternative to fully synthetic composites. Goat bone has unique properties that make it a valuable additive in composite materials, particularly for bio-composites.

SELECTION OF MACHINE TYPE:

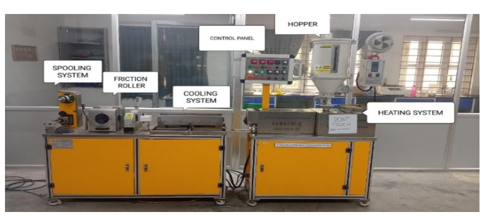

Figure 10 Single screw filament extrusion

The single-screw filament extruder machine is designed to handle both PLA and TPU materials, so the above machining apparatus is selected as shown in figure 10. The working principle of a single-screw filament extruder machine involves several stages that transform raw polymer materials, such as PLA and TPU biopolymers, into a continuous filament suitable for 3D printing.

RESULT AND DISCUSSION:
EXTRUSION OF FILAMENT FROM PELLETS:
Before enter the materials into the single screw filament extruder, moisture removal done by oven in 60°C at 200mins as shown in figure 11. Regular experimentation and adjustment may be Necessary to fine-tune the parameters based on the specific properties of composites and the desired characteristics of the final filament as shown in figure 12. The combination of filament is a PLA 80%, TPU19%, CAPRA HIRCUS Bone Powder 1% composites blended and filament thickness

1.75mm.
Figure 11 Moisture Removal Figure 12 Extruded Filament

PRINT THE TEST SAMPLES
Mechanical properties were comprehensively assessed for PLA-TPU Compounds in different loading modes including tensile, compression and bending According to the relevant ASTM standards as shown in figure 13. These tests were performed at ambient Temperature at a displacement rate of 1 mm/min. The conditions, geometry, Dimensions loading modes are presented as per the ASTM standards in table 1.

Figure 13 Printed Test Samples
Printing specifications for 3d printing such as 100% Infill density, lines Infill pattern, Print speed 50mm/s, 0.2mm Layer height, Wall/top/bottomthickness 0.8mm, Printing temperature 210°C, Bed temperature 60°C.

Table1.Printed by ASTM Standards

ASTM STANDARDS	LOADING MODE	GEOMETRY	DIMENSION (IN MM)
ASTM D638	Tensile	Dogbone	115x19x3.2
ASTM D695	Compression	Cylinder	12.7x12.7x25.4
ASTM D790	Flexural	Beam	127x12.7x3.2

MECHANICAL PROPERTIES:
TENSILE TEST

Figure 14 Tensile Test Samples

Table 2. PLA,TPU & CAPRA HIRCUS Bone compound Behavior under tensile mode of test

Sample details	Tensile strength (Mpa)	Elongation (%)	Reduction in area (%)
1	19.27	3.33	3.01
2	22.40	3.33	3.09
3	21.35	1.66	2.22
Average	**21.01**	**2.77**	**2.77**

The tensile strength for PLA80%,TPU 19%,CAPRA HIRCUS BONE POWDER 1% is 21.01Mpa & Elongation 2.77%.

COMPRESSION TEST:

Figure 15 Compression Test Samples

Table 3. PLA,TPU & CAPRA HIRCUS Bone compound Behavior under compression mode of test

Sample details	Compression load (kN)	Compression strength (Mpa)
1	2.80	8.68
2	2.11	6.54
3	2.38	7.38
Average	**2.43**	**7.53**

Compression load observed up to formation change is 2.43kN & compression strength 7.53Mpa.

FLEXURAL TEST:

Figure 16 Flexural Test Samples

Table 4. PLA,TPU & CAPRA HIRCUS Bone compound Behavior under flexural mode of test

Sample details	Flexural load (kN)	Flexural strength (Mpa)
1	0.03	34.60
2	0.03	34.60
3	0.04	46.14
Average	**0.03**	**38.45**

Flexural load 0.04kN & flexural strength 38.45Mpa.

CONCLUSION:

In this project work, for the first time, the mechanical properties experimentally for 3D printed PLA,TPU and CAPRA HIRCUS bone powder compounds with weight percentages of components. The mechanical tests was carried out in tensile, compressive, bending modes. The role of PLA concentration In mechanical properties was very effective and with the increase of PLA amount (80%), the strength increased in tensile (21.01Mpa), flexural (38.45Mpa), and compressive (7.53Mpa)modes. CAPRA HIRCUS Bone Powder (Goat bone powder) is smaller, denser, and more brittle but more bioavailable and ideal for quick absorption (hydrophobic). Due to faster degradation, Suitable for small-scale structural applications, scaffolds applications, bone graft material or surgical models.

FUTURE SCOPE:

1. Analysis the failure.
2. Change and develop the CAPRA HIRCUS bone powder preparation method and compositions.

3. Change the Filament extruder type and printing specifications.
4. Various combination of materials based on applications.

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