REPORT

Report on participation of the ICMR International Fellow (ICMR-IF) in Training/Research abroad.

1.	Name and designation of ICMR- IF	: Dr. Nitin Sahai, Assistant Professor
2.	Address	: Department of Biomedical Engineering, NEHU, Shillong-793022, Meghalaya
3.	Frontline area of research in which training/research was carried out	: Material characterisation and 3D printing for medical applications.
4.	Name & address of Professor and host institute	: **Dr. Peter Maroti** M.D., Ph.D. Deputy Director, Medical Skills Education and Innovation Center ; University of Pecs, 3D Printing and Visualization Center- Head; University of Pecs, Medical School, HU-7624, Pecs, Szigeti str.12
5.	Duration of fellowship with exact date	:12 Months(15/03/2023 to 14/03/2024)

6. **Highlights of work conducted**

i) Technique/expertise acquired.

During the fellowship tenure, I got hands-on training and exposure to different 3D printing methods through different types of printers for medical applications, including extensive material characterisation techniques. The short details are mentioned below: -

1. Fused Filament Fabrication (FFF): - Learn hands-on exposure to different Fused Filament Fabrication printers for printing Polymer and metal printing, which consist of the following.
   - **1.1. Craftbot Plus:-** Craftbot Plus mainly uses PLA and ABS materials. Can print Layer Thickness Different layer heights are recommended for each head, 200-micron layer thickness provides an ideal compromise between detail and print time. 100-micron layer thickness is the minimum that can be achieved for PLA and ABS, Print volume: 25x20x20 cm.
   - 1.2. **Craftbot 3**:-Independent dual-extrusion mode (when two printheads operate independetlly from one another): 18.7 x 25 x 25 cm
   - 1.3. **Craftbot Xl**: the CraftBot XL has more than twice the vertical axis of a single CraftBot, so it can print 44 cm objects instead of 20 cm

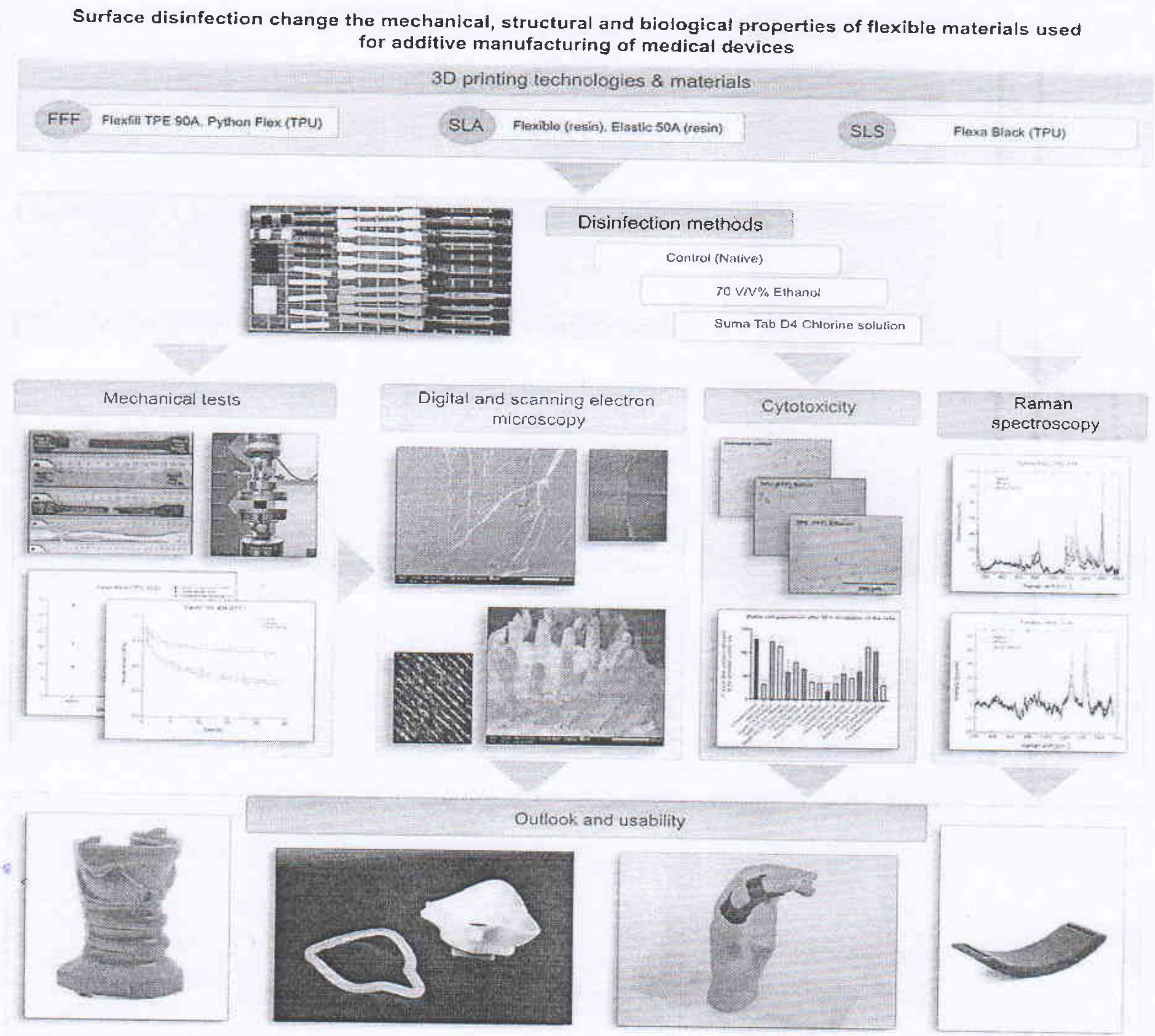
1.4. **Ultimaker 3**: Automatic nozzle lifting system and interchangeable print cores.
1.5. **Prusa I3 Mk3:** Equipped with a Filament Motion Sensor that detects when filament runs out during printing.
1.6. **Markforged X7:** Industrial 3D printer capable of printing composites with continuous fibre reinforcement
1.7. **Markforged Metal Printer:** Tool steel printing from developed CAD model

2. **Stereolithography (SLA):** -I got hands-on exposure to two different types of SLA printers, namely Formlabs Form 2 has a print volume of 145 X 145 X 175 MM, AND formlabs form 3 has a print volume of 145 x 145 x 185 mm.
3. **Selective Laser Sintering (SLS):** - Learned SLS printing with EOS FORMIGA P110 printer. In this printer, raw materials used can be either polystyrene or polyamide. The print volume is 200 x 250 x 330 mm, but larger models can only be printed in pieces.
4. **Material Characterization:** - Tensile Testing, Compression Testing, Flexural Testing, Hardness Testing, Shear Testing, and Torsion Testing using a ZwickRoell material testing machine. DSC, SEM
5. **Simulation-based medical teaching and learning laboratory:** The laboratory's main objective is to improve the manual abilities of medics, both graduates and post-graduates.

ii) Research results, including any papers, prepared/submitted for publication

➢ During the fellowship period, I participated in three research studies some papers were published, and some were submitted, which are mentioned below.

1. In the First study, we studied the effect of commonly used cost-effective disinfectants, ethanol (70 V/V%), and chlorine solutions on the mechanical and thermal properties of flexible 3D-printed materials. The following materials were tested before and after 5-cycle surface disinfection: Flexfill TPE 90A, Phyton Flex (TPU) for material extrusion, Flexible (resin), Elastic 50A (resin) for vat photopolymerisation and Flexa Black (TPU) material for powder bed fusion technology. Mechanical tests included tensile, compression, Charpy impact, flex resistance and stress relaxation tests, Shore A hardness and volume measurements. The structure was analysed using scanning electron microscopy (SEM)and Raman spectroscopy. The cytotoxicity was assessed using a A549 cell viability assay. The results show that after disinfection, significant changes occurred mainly in the tensile and Shore A properties, such as the tensile strength of the disinfected Flexible (resin) materials was 3.44 MPa ± 0.51 MPa (ethanol) and 2.62 MPa ± 0.31 MPa compared to the native 2.02 MPa ± 0.24 MPa. Interestingly, the applied surface disinfectants can negatively affect biocompatibility. Medical devices have been designed and fabricated based on the findings. Our findings can guide the potential applications of commonly used 3D printed flexible materials in the biomedical field.



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2. In the second study, we investigated and compared the mechanical, structural, and thermal properties of 3D printed PA12 produced by desktop and industrial printers using fused filament fabrication (FFF) or selective laser sintering (SLS). Samples were prepared using Prusa I3 MK3S+, Craftbot 3, Markforged X7^{TM}, Sinterit Lisa and EOS Formiga P110 printers. Mechanical testing of PA12 included tensile, flexural, Charpy impact, Shore hardness, torsion, and water absorption tests. Thermal, rheology and structural properties were determined by differential scanning calorimetry (DSC), melt volume rate measurement and scanning electron microscopy (SEM). Significant differences were observed between desktop and industrial printers, particularly for SLS, such as the impact strength was 18.9 kJ/m^2 ± 1.50 kJ/m^2 for SLS desktop and 44.5 kJ/m^2 ± 2.74 kJ/m^2 for SLS industrial printer. Interestingly, industrial CFR printers showed lower mechanical results than FFF printers in most cases.

3. In third study, mechanical properties (tensile, three-point flexural, Shore D hardness and Charpy impact tests according to ISO standards) and electrical properties (resistance, signal transmission, resistance measurements during cyclic tensile and temperature tests) were investigated on polylactic acid (PLA)-based, acrylonitrile butadiene styrene (ABS)-based, thermoplastic polyurethane (TPU)-based, and polyamide (PA)-based conductive filaments with carbon-based additives. Scanning electron microscopy (SEM) was implemented to evaluate the results. The conductive ABS specimens have a high gauge factor between 0.2% and 1.0% strain. All tested materials, except the PA-based conductive composite, are suitable for low-voltage applications such as 3D-printed EEG and EMG sensors. ABS-based and TPU-based conductive composites are promising raw materials suitable for medical applications.

List of Articles published: -

1. Kinga Kardos, Roland Told, Attila Pentek, **Nitin Sahai**, Krisztina Banfai, Andras Vizi, Arnold Koltai, Peter Szabo, Zsuzsanna Gurdan, Judit Bovari-Biri, Judit E. Pongracz, Elek Telek, Andras Lukacs, Peter Maroti, ***Surface disinfection change the mechanical, structural and biological properties of flexible materials used for additive manufacturing of medical devices***, Materials & Design, Volume 237, 2024, 112616, **(SCIE Impact Factor 8.4(2024)).**

List of Articles Submitted for publication: -

1. Shiroud Heidari, Behzad and Dodda, Jagan Mohan and El-Khordagui, Labiba and Focarete, Maria Letizia and Maroti, Peter and Toth, Luca and Pacilio, Serafina and El-Habashy, Salma and Boateng, Joshua and Catanzano, Ovidio and **Sahai, Nitin** and Mou, Lingjun and Zheng, Ming Hao, Emerging Biomaterials and Technologies for Advancing Surgical Meshes.
2. Comprehensive study of Mechanical and Electrical Properties of Conductive Polymer Composites for Medical Applications through Additive Manufacturing'
3. Comparative analysis for mechanical and thermal properties of 3D printed polyamide using industrial and desktop additive manufacturing technologies

iii) Proposed utilization of the experience in India

I aim to propose an establishment to establish a medical material characterisation facility in North East India, based on the knowledge and expertise gained through an international fellowship at the 3D Printing and Visualization Center, University of Pecs, Hungary. The facility aims to provide advanced material characterization services for developing and evaluating medical devices, biomaterials, and tissue engineering scaffolds. This will contribute to the advancement of medical technology in India and enhance the quality of healthcare services.

The development and evaluation of medical devices require thorough characterization of their material properties, including mechanical, physical, and biological performance. In India, there is a growing demand for such services, but the availability of specialised facilities is limited. This gap in infrastructure hinders the innovation and adoption of advanced medical technologies in the country.

The proposed medical material characterisation facility will address this need by providing comprehensive testing services for medical materials. The facility will focus on the following objectives:

1. Provide advanced material characterisation capabilities: The facility will be equipped with state-of-the-art instrumentation for mechanical testing, physical property analysis, and biological evaluation of medical materials.
2. Support the development of medical devices and biomaterials: The facility will provide testing services for developing and optimising medical devices, biomaterials, and tissue engineering scaffolds.
3. Contribute to the advancement of medical technology in India: The facility will collaborate with researchers, manufacturers, and regulatory bodies to promote the use of advanced materials in medical applications.

The facility will establish a training program to equip personnel with the necessary expertise to operate the instrumentation and conduct material characterisation studies. The program will involve theoretical knowledge imparted by experts and hands-on training on the facility's equipment. The establishment of the medical material characterisation facility will have significant impact and benefits, including:

- Enhancing the quality of medical devices and biomaterials.
- Promoting innovation in medical technology
- Supporting the growth of the medical device industry.
- Improving healthcare outcomes: The availability of advanced materials and devices will improve patient care and outcomes.

18/3/2024

Signature of ICMR-IF

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