Ultrasonic Assisted Coating of Fused Deposition Modeling Based Poly Lactic Acid Scaffolds for Improved Load Bearing Strength

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INTRODUCTION: Scaffolds play a crucial role in biomedical engineering by providing a framework that facilitates the growth of cells and tissues. The porous structure of scaffolds assists in the attachment of cells for successful tissue regeneration. Fused Deposition Modeling (FDM) has emerged as an extrusion-based additive manufacturing technique for the fabrication of complex scaffolds with controlled porous architecture [1]-[3]. However, scaffolds fabricated using this technique often lack mechanical strength, limiting their application in regenerative medicine. In this study, the authors addressed this limitation by applying biocompatible polydopamine, obtained from the oxidation and self-polymerization of dopamine in a weakly alkaline buffer solution.

METHODS: A total of 25 (n = 25) Poly Lactic Acid (PLA) based diamond scaffolds with a unit cell size of 5 were fabricated using the FDM process at a constant set of printing parameters. During the direct immersion coating of polydopamine over PLA, the accumulation of coating particles was observed with an increase in coating concentrations. The authors investigated the effect of ultrasonic vibrations on coating deposition and the mechanical properties of scaffolds. The ultrasonic setup (Acquired from: Unitech Allied Automation, India; Model No.: UAA/UM with input power of 800W) was used for ultrasonic assisted coating at varying levels of coating parameters (e.g. ultrasonic power varying from 0% to 100%, coating concentration in the range of 1 mg/ml to 6 mg/ml, and exposure time varying from 0 minutes to 150 minutes).The Response Surface Methodology (RSM) based Design of Experiments (DOE) approach was used to study the effect of ultrasonic-assisted coating parameters on the mechanical properties of scaffolds. The coating of porous scaffolds based on DOE was followed by compression testing of scaffolds using a Universal Testing Machine (UTM 7200 Series, Manufactured by: DAK System Inc.). Analysis of Variance (ANOVA) was executed through Minitab to establish a predictive statistical model for compression strength. This model is applicable to assess the compression strength of scaffolds coated within the parameter range outlined in this investigation. Furthermore, ANOVA was employed to identify the parameters that exert a significant influence on the compression behavior of scaffolds, with a significance level of 95%. A comparison study was also performed for determining the improvement in compression strength of uncoated scaffolds with application of ultrasonic assisted polydopamine coating.

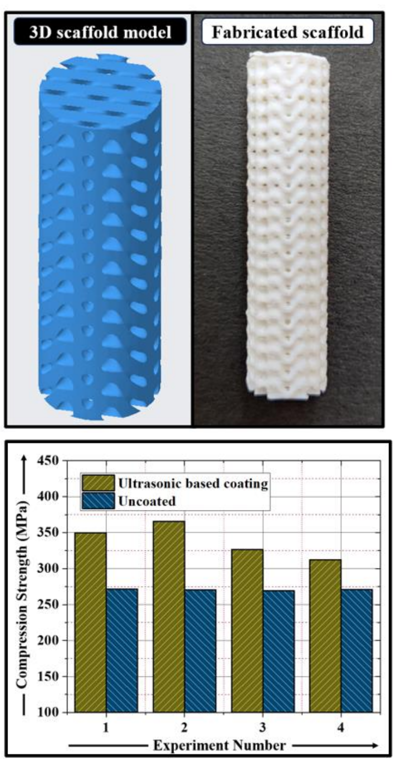
RESULTS: The findings suggested major contribution of ultrasonic power in affecting the compression strength of polydopamine coated PLA scaffolds. For comparative study, specific values of ultrasonic power, coating concentration and exposure time was selected (Table 1) from the range of parameter values described in the study. For diamond based PLA scaffold with unit cell size 5 (Figure 1(A)), it was evident that the ultrasonic based coating process provided improvement in compression strength of scaffolds, ranging from 35.15% to 15.22%, in comparison to the compression strength results obtained for uncoated PLA scaffolds (Figure 1(B)). This can be contributed to the ability of ultrasonic vibrations in limiting accumulation of polydopamine particles at the container base with increase in coating concentrations.

Table 1 Comparison study based on compression strength of PLA scaffolds under uncoated and ultrasonic based coating conditions

Experiment Number	Process Parameters			Compression Strength (MPa)	
	Ultrasonic Power (%)	Coating Concentration (mg/ml)	Exposure Time (min)	Ultrasonic based coating	Uncoated
1	100	3.5	75	349.471	271.392
2	75	5	100	365.765	270.629
3	50	2	90	326.512	269.047
4	25	4	60	312.287	271.027

(A)

(B)



DISCUSSION: FDM based PLA parts often lack mechanical strength, which can be enhanced by application of biocompatible polydopamine coating. This is due to the cross linked structure of polydopamine that undergoes covalent interactions with the molecular structure of PLA, thus, enhancing the interlayer bonding of the FDM based structure [4]. The porous structure of scaffolds is highly important for biomedical based tissue engineering applications [5]. The increase in ultrasonic power provided forced striking of polydopamine particles against the scaffold surface that constrained accumulation of coating particles at the container bottom and enhanced deposition of polydopamine in the porous structure of scaffold, thereby, improving the compression strength of the FDM based scaffolds. The reported literatures [6],[7] based on ultrasonic assisted deposition of nickel boron and titanium carbide coatings suggest uniform particle dissolution and thick coating deposition with ultrasonic vibrations. Thus, the current findings from this study are in agreement with the reported findings.

SIGNIFICANCE/CLINICAL RELEVANCE: Ultrasonic assisted coating of fused deposition modeling based poly lactic acid scaffolds is a valid technique to improve the mechanical characteristics of load bearing scaffolds for tissue engineering applications.

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Figure 1. (A) 3D scaffold model with FDM based fabricated scaffold; (B) Compression strength of scaffolds under uncoated and ultrasonic based coating conditions (corresponding to Table 1)