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Surface processing of additively manufactured articles for the improvement of antimicrobial properties

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Abstract: Antimicrobial study was conducted to test the surfaces of additively manufactured (AM) polyamide parts via powder-bed fusion. As printed parts exhibit rough, porous and powdery surfaces providing a favorable breeding ground for bacteria and fungi. This creates an issue for AM parts intended for use in medical and other highly controlled applications. A novel surface processing method able to seal and smooth surfaces was used to improve antimicrobial properties of parts. Processed parts were tested for microbial growth and the results were compared to the unprocessed parts. This study presents the obtained results and discusses possible applications of this method.

I. Introduction

Use of 3D printing for medical applications has increased significantly as a response to the Covid-19 pandemic that has resulted in shortage of medical articles including masks, shields, splitters and various components for the respiratory systems. AM offers the capability to rapidly produce necessary medical articles in time of increased demand and shortages. It is faster for the local institutions to receive specialized parts by 3D printing them at the point of use rather that adhering to coordinated response channels with longer lead times created by excessive demand. Therefore, Additive Manufacturing has become a resource of significant importance, which must be utilized and understood better.

I.I. Overview of current methods

AM articles produced via powder-bed fusion (PBF) result in rough, powdery, and porous surfaces due to the layer-by-layer nature of the print process (Fig 1 a).

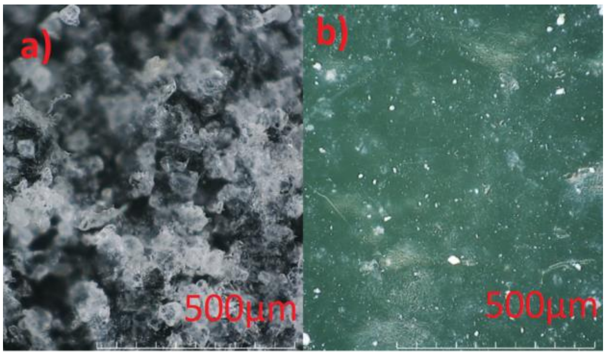

Figure 1: a) as-printed rough surface and b) surface smoothed with BLAST technology

This promotes the accumulation and growth of bacteria, fungi and increases the risk of the loose polymer particles entering the respiratory system [1]. This issue limits the use of printed articles for respiratory use and direct skin contact of many medical devices.

Current post-processing methods for AM components involve coating and mechanical abrasion techniques. The latter does not seal the surface and creates polymer micro-fibers that can enter the respiratory system and hence is not adequate for smoothing articles to be used for medical respiratory applications. Antimicrobial coating of parts can create a smooth and sealed surface; however it significantly adds to the post-processing costs.

Another option is to mix the powder with antimicrobial particles, however that limits the material choice, and may reduce the needed mechanical properties of the material.

I.II. A novel surface treatment

Additive Manufacturing Technologies, a British manufacturer of smart post-processing systems, has introduced a novel vapor-based surface smoothing technology called BLAST (Boundary Layer Automated Smoothing Technology). The BLAST process takes place under controlled environment and can uniformly smooth and seal surfaces of difficult to reach areas such as internal cavities and piping systems [2]. The process works on a wide variety of thermoplastic polymers, including frequently used PA12, PA11, TPU, ABS, ULTEM and many more.

During the BLAST process, the top layer of the polyamide part is reflowed resulting in smooth, sealed and easy to clean surface (Fig. 1b). The processed surfaces were shown

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to have passed cytotoxicity and skin irritation tests according to ISO 10993-5 and ISO 10993-10 respectively. Among advantages of the method is complete removal of loose semi-sintered particles, making it a perfect solution for respiratory PPE.

II. Material and methods

A total of 12 parts made from Polyamide-12 were tested. 6 samples were processed with BLAST technology in the PostPro3D machine and 6 were left unprocessed (as-printed). The tested samples were printed with HP Multi-Jet Fusion (MJF) technology. For comparison surface roughness of both processed and unprocessed samples was measured using Mitutoyo Surftest SJ-210 surface roughness analyzer. Five measurements at different areas of each surface were made before and after processing and the average taken. This was performed in accordance with ASTM standard ASTM D7127.

Determination of antimicrobial activity was performed based on MOD ISO 22196:2011 standard methodology. Test duration was 24 hours (±1) at 35ºC (±2) under a relative humidity of >90%. The samples were sterilized under dry heat at 65°C for one hour and tested against Gram-positive and Gram-negative bacteria (MRSA and E. coli respectively). Polyethylene film cover slips of size 40x40mm and thickness of 0.045mm were used with inoculation volume of 0.1ml.

III. Results and discussion

Surface roughness comparison of processed and unprocessed samples is shown in Fig.2. BLAST processing allowed parts to achieve injection-molded-like surface with Ra values below 1µm. Note the processed surfaces also exhibited good repeatability as demonstrated by the small standard deviation.

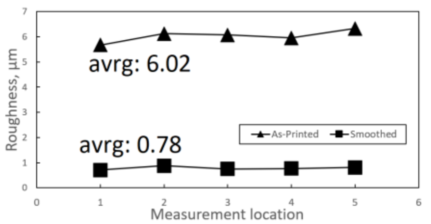

Figure 2: Surface roughness results

Antimicrobial results are given in Table 1. The analysis has shown that the processed parts have passed the antimicrobial test showing a reduction of bacterial growth quantified as 99.88% against MRSA and 99.78% against E. coli while the un-processed parts have failed the test showing a limited reduction of MRSA and a significant growth of E. coli over time.

The improvement in antimicrobial properties of the parts can be explained by the removal of favorable environment for the bacterial growth: elimination of pores, loose powder and rough enclosed areas of uneven surfaces that would be easy for the microbes to attach and grow (Fig. 1 a). Physical nature of the surface modification leads to the reduction of the bacterial attachment and growth and the obtained improvement is comparable to the use of antimicrobial particles mixed in the material powder [3] and thus when used in conjunction may create highly effective long-lasting antimicrobial part surfaces.

Table 1: Antimicrobial test results

		Sample			
		As-printed		**BLAST processed**	
Test bacteria		MRSA	E. Coli	MRSA	E. Coli
Contact time	*0 Hrs*	8.15 x10^4	9.08 x10^4	8.15 x10^4	9.08 x10^4
	24 Hrs	9.60 x10^3	7.71 x10^5	≤100	2.00 x10^2
Reduction against Initial	*Log$_{10}$*	0.93	Growth	≥2.91	2.66
	%	88.23%	Growth	**≥99.88%**	**99.78%**
Interpretation		FAIL		PASS	

**Numbers represent Colony Forming Units at representative contact times.*

Previous studies performed at AMT have shown the effect of the post-processing in mechanical properties of similar 3D-printed parts.[4] The results showed no loss in Ultimate Tensile Strength in processed samples. Elongation at Break (EAB) of the tested samples significantly increased, whereas the Young's Modulus decreased. The increase in EAB is attributed to the reduction of crack initiation sites on the polymer surface due to the removal of surface porosity. Moreover, parts processed in the PostPro3D machine exhibited negligible dimensional variation resulting in the retention of part tolerances and retention of fine feature details.

IV. Conclusions

The results prove that vapor-type surface smoothing process BLAST effectively reduces the bacterial attachment and growth on the processed surfaces of Polyamide 12 Additively Manufactured parts. This one-step process is more efficient that the standard surface post-processing and coating methods and can enable wider usage of Additively Manufactured parts for medical applications, especially for - respiratory use. Therefore, future work will be focused on further certification of the proposed method in medical application.

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Author's statement

Conflict of interest: Authors state no conflict of interest.

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