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Editorial

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Making our parts work harder – getting started with functional materials for 3D printing

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"Despite the clear benefits of increased or improved functionality in 3D-printed parts, the process to achieve this is not a simple one, and there are many stages at which one may encounter hurdles."

Tweetable abstract: New material combinations provide potential for major improvements in #3D printing/#AdditiveManufacturing, but how do we get started with them and what are the potential stumbling blocks? Find out here!

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Since their commercialization in the late 1980s/early 90s, 3D-printing processes have been known for their ability to produce complex geometries more economically and efficiently than conventional manufacturing processes. This, combined with their use in production of one-off, often personalized, components mean they have been increasingly embraced by the medical sector. Initially used for visualization and prototyping purposes, these techniques are now being applied to produce end-use components such as prosthetics or medical implants, and in tooling applications such as surgical guides [1–4].

More recently, we have seen increasing emphasis on moving beyond the geometric and personalization capabilities of 3D-printing processes, and toward the incorporation of additional functionality via more complex materials. Materials which are bioactive, bioinert or bioresorbable have received increasing attention, particularly for their use for medical implants or in tissue engineering [5,6]. Other areas of interest might include antibacterial or antiviral functionality, flame retardancy or enhanced mechanical integrity. While in some cases we may be able to produce parts directly from a material possessing the required functionality, in many cases we rely on the inclusion of extra additives (or fillers) within a base material. By taking this approach we can maintain the processability benefits of a known 3D-printing material, while also achieving the extra functional performance desired.

Despite the clear benefits of increased or improved functionality in 3D-printed parts, the process to achieve this is not a simple one, and there are many stages at which one may encounter hurdles. Of course, there are significant regulatory steps required to bring these materials into medical use, but what happens at the earlier research stages of their development and what does it take to get started? The specific techniques and methods for developing these new material combinations will vary depending on the specific choice of 3D-printing process, but it is possible to specify a general approach, broken down into a series of discrete steps applicable across multiple process types.

Using the polymer laser-sintering process as an example, this article will highlight the main steps toward the early-stage testing and development of novel material combinations. In this case, the focus is the incorporation of a specific additive into a base polymer to provide antibacterial functionality, preliminary results of which can be found in our initial research in this area [7].

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Understanding the process

The starting point for any material-based developments or trials must necessarily be to understand the specific 3D-printing process being used. Most 3D-printing processes have their own nuances and intricacies, and a range of requirements a material must meet in order to produce high quality, repeatable, parts. In the laser-sintering process we need multiple factors to come together to provide acceptable part quality [8]. Can we deposit the powder in a smooth, densely packed layer? When molten, is the viscosity of the polymer low enough to allow the particles to merge together fully, but sufficiently high that the resultant layer retains its shape? Are the thermal properties suitable? Whichever process you are working with, understanding these aspects early on will significantly aid decision making throughout.

Make or buy?

While it might seem to be the best way to achieve the exact results you want, developing a material from scratch is time consuming, requires specific expertise and in many cases is not necessary for a specific application. Most often the best approach will be to use combinations of 'off-the-shelf' materials as a starting point and see how close the resultant parts are to what we are looking for. We might then look to modify these materials in some way, but often an existing solution proves to be sufficient for our needs.

In the case of our research, we started with both a commercially available antibacterial additive (specifically a silver-phosphate glass) and base polymer powder (here, Nylon-12), to test our underlying concept and learn more about the effect of the additive. In our current work (not yet published) we are collaborating with a team at the University of Nottingham to develop and test bespoke additives in order to tailor their antibacterial performance [9]. By following this approach we were able to establish a baseline from the commercial material and use this to inform our decisions on future directions.

Concentrations matter

It may sound obvious, but to be a viable solution a material must 'behave' well in the 3D-printing process. In other words, the inclusion of our functional additive at percentages high enough to achieve the effect we want, must not inhibit the performance of the 3D-printing process itself. In some cases, as with our antibacterial work, relatively small (~1%) quantities of the functional additive can be sufficient. However, in other cases the quantities of the additive needed to obtain the relevant performance may be high enough to disrupt the manufacturing process [10], or even prohibit part production. Understanding the levels of filler needed to generate a desired effect will help to establish (or perhaps eliminate) its potential suitability before moving into in-machine trials.

Does it weaken our parts?

One of the biggest frustrations when working on materials for 3D-printing is the likelihood of fixing one aspect at the detriment of another. It is often the case that the inclusion of an additive will lead to the change we are looking for in one property, combined with a negative effect on another. For example, a filler intended to deliberately increase the stiffness of a part might also result in a corresponding decrease in ductility, while an additive intended to promote good powder deposition might lead to a subsequent decrease in particle coalescence and subsequent part strength [11]. Understanding any differences caused by the inclusion of these additives, as well as understanding the properties needed for the final application of your parts, will allow you to make informed decisions about the suitability of a particular approach for any given situation.

Is our additive evenly dispersed?

Different methods of mixing or combining our materials tend to lead to different levels of uniformity in their dispersion [12]. Although not always the case, in general we would like our material to be homogenous throughout our parts rather than obtaining different concentrations in different areas. For our particular focus on antibacterial functionality this is particularly important. If we can be certain our additive is distributed well throughout our parts, we can be more confident in achieving consistent performance; if the surface of a part is damaged, the newly exposed areas of the part should remain functional.

To investigate this, we can draw on techniques more commonly seen in medical applications. In particular, micro-computed tomography has seen increasing use as a technique for analyzing levels of porosity in 3D-printed parts, but depending on the additive used, it can also be used to identify the dispersion of our additive throughout our parts [13–15]. If the results show a homogenous dispersion throughout the parts, we can be confident that our

approach (simple mechanical mixing of our additive and base polymer) is sufficient. Conversely, a non homogenous distribution may indicate a need to change to a more complex or robust approach.

Do we harm human cells?

Up to this point, we have focused heavily on how well our approach is working from a manufacturing perspective, but in many applications, we also need to understand whether there is potential to harm human cells. Cytotoxicity tests [16] are therefore an important part of understanding the behavior of our parts when they come into contact with people. While this is especially true in a medical setting, there are also implications when considering products across a whole range of industry sectors; if in any doubt, it is better to test and be sure!

Do the resultant parts show the functionality we expect?

It is only at this stage, having passed this series of potential barriers, that we finally start to answer our original research question – does our chosen material combination actually behave how we expect it to? In some cases, there may be standard test procedures you can follow in order to establish the performance, while in others it may be necessary to develop new tests specifically related to the intended application of your parts [7]. What is critical at this stage is having a solid understanding of how these parts need to perform, so you can be certain they will work in practice.

What we have found in our work so far is that our approach works well under certain conditions and not under others, meaning the next steps are to understand in more detail the nuances and limits of this material combination. What types of bacteria is it most effective against? What type of environments (temperature, nutrients etc.) give us the best results? How long do the antibacterial effects last for, and can we control these timescales by modifying the type or quantity of our additive?

Final comments

There is no doubt that new and varied material combinations will play an important role in increasing the usefulness of 3D-printing techniques, both in medicine and more broadly. As the processes themselves develop further, we are likely to see increasing numbers of applications taking advantage of combination of both the geometric capabilities of 3D printing and novel materials – the outlook is exciting!

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