FABRICATION OF ACOUSTIC ABSORBING TOPOLOGIES USING RAPID PROTOTYPING

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1. INTRODUCTION

Porous absorbing materials traditionally constitute fibrous, granular or open celled foam material types. The manufacturing methods associated with these materials, impose limitations on the topology of the porous microstructure. Pore size and shape are determined by pseudo-random processes such as the layering of bonded fibrous filaments, packing of granulated materials, or the nucleation and growth of gas bubbles within a polymer matrix. These processes only allow a limited level of control over the topology of the porous microstructure, restricting the structure types that can be realised, and introducing uncertainty into the prediction of their acoustic properties. Theories based on extensive empirical measurements such as those described by Delany & Bazely [1], disregard the geometric differences between individual pores by deriving correction factors from measurements of bulk material samples; however, this limits their applicability. Theoretical models which aim to be more generic, describe the visco-thermal effects within individual pores (e.g. Allard & Champoux [2]), but require the use of generalized pore shape factors or characteristic lengths, and an estimation of the distribution of pore sizes, which are often derived from bulk material properties.

Computer controlled additive manufacturing processes are commonly referred to as ‘Rapid Prototyping’ (RP). These processes precisely control the deposition of material to build any virtually given component geometry. Applying these techniques to the manufacture of acoustic absorbers has the potential to improve pore shape definition, optimize porous structures and deliver a more uniform pore size distribution. RP encompasses a broad family of different processes. The processes are similar in that the additive fabrication machines are driven directly from a computer model. They produce three dimensional shapes from two dimensional cross sectional slices sequentially bonded together from the bottom to the top of the part. The processes differ in their method of producing each cross sectional slice. Some processes selectively solidify, sinter or cut a bulk build material, while others selectively deposit material where it is required. One such process known as Fused Deposition Modelling (FDM) selectively deposits a fine thermoplastic filament and can vary the thickness and spacing between filaments, as well as the angle between filaments on adjacent layers. This process, illustrated in Fig. 1, allows the fabrication of a uniform porous material with a definable structure. The filament diameter can be fabricated down to 0.305mm, 1-2 orders of magnitude higher than that of traditional fibrous materials.

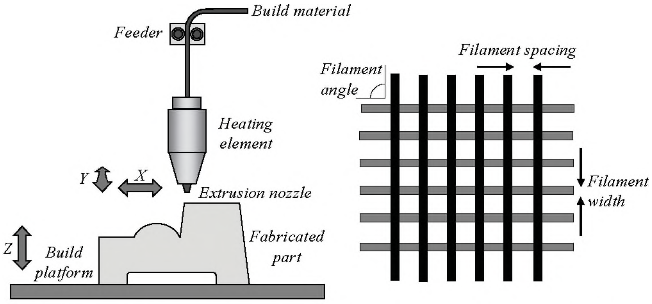

Fig. 1. FDM process schematic and porous structure variables.

The materials and characteristics of each RP process vary, and some are more suited than others for the direct fabrication of acoustically absorbing topologies. All RP processes, however, introduce benefits for design and fabrication that go beyond many traditional methods of manufacture. In particular, the production of complex re-entrant shapes is possible without the requirement for tool clearance which is critical for the realization of intricate or customized acoustic absorbers.

2. FDM POROUS STRUCTURES

To investigate the potential use of RP in the fabrication of acoustically absorbing topologies, porous samples were produced using the FDM process. Samples with different porosities were produced by varying the filament spacing. Samples 25mm thick were produced with 5%, 10%, 25% and 50% porosity, from filaments 0.508mm thick, with a 90 degree filament angle. The absorption properties of each sample were measured using an impedance tube in accordance with BS EN ISO 10534-2 [3]. Two samples of each configuration were produced: one 100mm in diameter and one 28mm in diameter to allow testing using low and high frequency impedance tubes. The measured absorption coefficient, α for each configuration is depicted in Fig. 2.

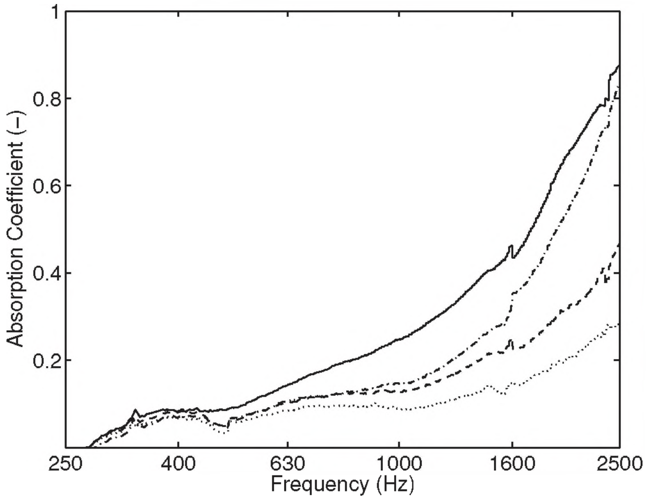

Fig. 2. Measured impedance tube absorption for porous FDM samples (porosity: —— 5%, –·–·· 10%, – – – 25%, ······· 50%).

The absorption results show that a porous structure produced using FDM is capable of achieving significant absorption over 1600Hz. The unconventional pore structure is unlike traditional porous materials in terms of regularity, porosity and fiber size and consequently the comparison of these results against existing theoretical models is difficult; however, a trend of increasing absorption can be noticed as the porosity decreases. Fig. 2 indicates that the acoustic properties of the test samples can be altered through changes to the manufacturing process parameters.

3. FDM POROUS STRUCTURES FOR DAMPED RESONANT ABSORPTION

The relatively large fiber diameter limits the production of small pore sizes to samples with low porosity. A level of flow resistivity high enough to promote porous absorption, therefore, is only possible with the lower porosity samples. The modest flow resistivity characteristics associated with the higher porosity samples, while not immediately suited to porous absorption, may be used to add resistance to Helmholtz type resonant absorbers. The addition of resistance dampens the resonant effect, broadening the bandwidth of effective absorption. This additional application was investigated through the fabrication of a resonant test sample consisting of perforations 4mm in diameter, 5mm in length, arranged with a 12% open area and a 45mm backing air space. The perforations were covered with an 8mm thick porous layer, with 25% porosity. Both the resonant and porous elements of the test sample were fabricated autonomously in a single FDM build, from the same material. The sample was 100mm in diameter for compatibility with the large impedance tube; consequently the measurable frequency range was restricted to below 1600Hz. The measured absorption coefficient for the damped resonant absorber is given in Fig. 3.

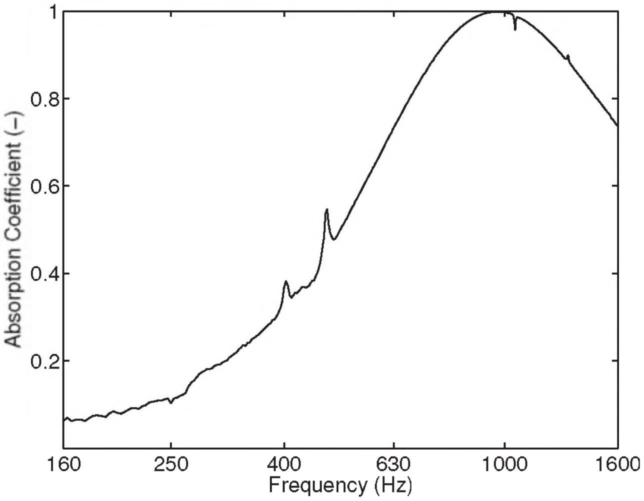

Fig. 3. Measured impedance tube absorption for FDM damped resonant absorber.

The results show that the combined resistive and resonant elements provide significant low frequency resonant absorption over 500Hz. Comparing the measured results to theoretical resonator models indicates that the porous covering offers a flow resistance of 5435 Pa s m^{-2}.

4. CONCLUSIONS AND DISCUSSION

The FDM process has been used to demonstrate the potential of a porous structure, whose characteristics can be established before manufacture. Various acoustic properties can be obtained by changing the manufacturing process parameters. Different configurations have been shown to exhibit significant high frequency absorption, or provide damping to low frequency resonant absorbers.

The ability to accurately produce a uniform, definable pore structure removes much of the uncertainty associated with the prediction of a porous material's acoustic properties, reducing variability between the prediction and performance of fabricated products or parts. It also presents a potential method of validating porous material theoretical models. There is potential to produce topologies with different pore shapes or with variable porosity throughout a single sample. Further investigation into these structure types, the effect of other FDM process parameters, and the application of theoretical models is needed to fully ascertain the potential benefits offered by this technology.

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