Applicability of chemical vapour polishing of additive manufactured parts to meet production-quality.

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Abstract

The Fused Deposition Modelling (FDM) method is the most rapidly growing Additive Manufacturing (AM) method[1]. FDM employs a 2.5D deposition scheme which induce a step-ladder shaped surface definition [2], with seams of the individual layers clearly visible[3]. This paper investigate to which extend chemical vapour polishing can be applied to eliminate the layered surfaces from FDM, so that a polished surface quality is obtained. It is quantified to what extend parts can be vapour polished and how geometrical and mechanical properties alter. The fundamental question is whether the surfaces of FDM manufactured parts can be taken from their current quality into the precision engineering domain.

1. Introduction and Method

Previously attempts to eliminate the layered definition of inclining surfaces of FDM parts include NC machining [4]. Whereas this approach is feasible, the geometrical freedom inherent from the AM process is lost, as geometries must be designed for subsequent NC profiling. The most common engineering-grade polymer for FDM is Acrylonitrile Butadiene Styrene (ABS)[1]. ABS is soluble in a variety of solvents, and recent studies show acetone vapour polishing can be achieved [5,6,7]. This paper aim to extend these studies so a deeper understanding of the mechanical and geometrical effects of chemical vapour polishing is gained. Two degradation mechanisms are studied: Mechanical and geometrical. The alteration of geometry was investigated, to determine to which extent a controlled polishing can be achieved. The geometrical verification is performed by means of a calibrated 3Shape Q640 line-laser based optical 3D scanner. Traceability is maintained, by verification against a spherical calibration artefact [8]. Solvent-based vapour polishing of ABS is an aggressive treatment of the thermoplastic, and it was questioned, to which extent mechanical properties alter and possibly deteriorate. This is investigated by tensile testing of polished and unpolished parts, parallel to and as a normal to the direction of the manufactured layers. A cross-sectional dissection of the specimens is performed to investigate if the mechanical alteration can be accounted for.

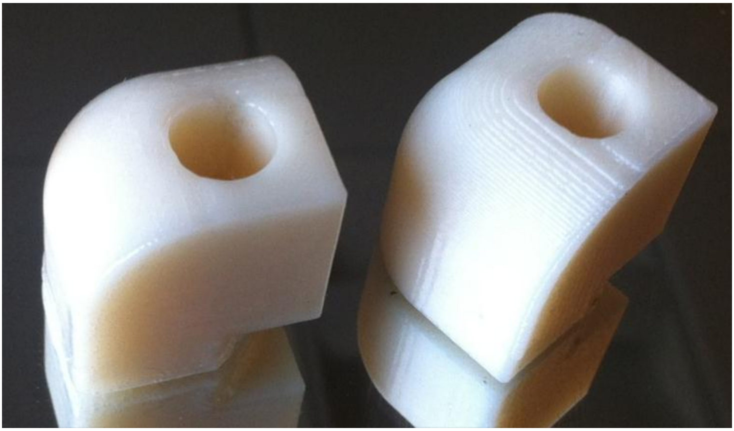

Figure 1: Left: Geometry #1, vapour treated Right: Geometry #1, untreated

2. Specimens and Preparation

Two test geometries was made in ABS by FDM from 250µm layers. Test geometry #1, seen on fig. 1, is a gauge-block measuring 20x20x20mm, with features designed to be eroded during vapour treatment. 11 specimens was measured prior to, and following the vapour polishing process. The process consisted of by a thermally induced, saturated acetone vapour cloud in a specimen chamber. Each specimen was treated individually. The polishing procedure was terminate, when by inspection, no layered structure is visible on the surface of the specimen. Test specimen #2 is designed following the ISO 527-1 *Test Method for Determining Tensile Properties of Plastics*. Two groups of 22 specimens were produced from which 11 were treated. One group was manufactured with layers parallel to the load direction. The second group with layers normal to the load direction. The termination criterion for the treatment was the same as for the previous specimens. Specimens rested 60 days prior to tensile testing, based upon knowledge from solvent-based welding of ABS using acetone, where it is suggested that specimens are cured for 60 days. [9]

3. Results

Geometrical alterations was predictable with sharp corners rounded from to the vapour polishing procedure to a magnitude that is comparable to the layered surface structure of the untreated specimen of 250µm. Thus, the radii of corners following vapour polishing was in the order of 150-300 µm. It was found that the treated parts would swell ≈1% from the treatment procedure, deteriorating geometrical tolerances.

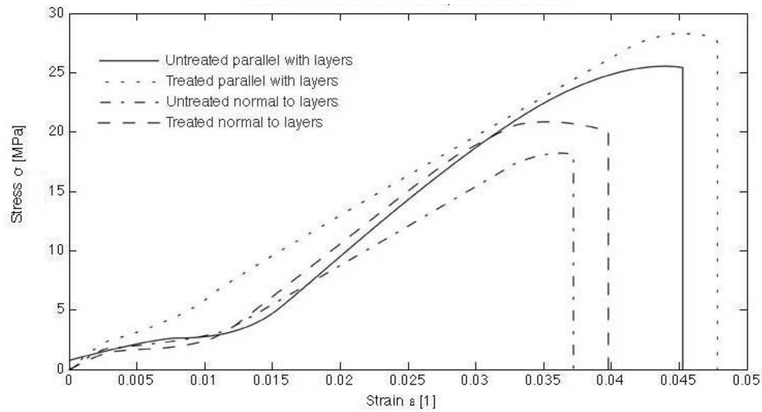

Figure 2: Normalized & averaged stress-strain, virgin and vapour treated specimens

It was found that chemical polishing slightly increases the mechanical strength of the specimens, as seen on fig. 2. There is a general increase in overall strength of the parts. This is accounted for as a mechanism in which vapour reaches the very core of

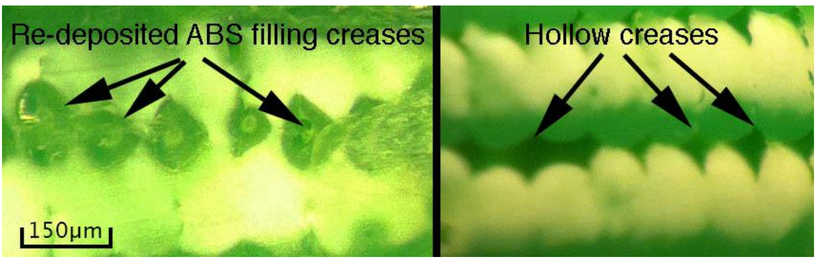

Figure 3: Cross-sectional dissection Left: vapour treated Right: untreated

The geometry, further fusing together each individual strand of ABS from which the part has been woven. Fig. 3 shows how dissolved and re-deposited ABS form in the creases between filament strings. Most noticeable is a strength increase normal to the layers, making tensile strength more uniform.

4. Conclusion & Summary

It was found that geometry is affected primarily by an erosion of sharp edged features. This happens in a magnitude that is related to the solvent exposure required to remove the layered structure from the surface. At 250 µm layers, corner-erosion was in the magnitude of 150-300µm. Deterioration of the overall geometrical dimensions was found to be ≈1%, as swelling from acetone absorption. Whether swelling will fade over time is inconclusive. Tensile strength was increased in specimens that had been treated with acetone vapour. Microscopy indicated a stronger fusion of individual strands of ABS. A redeposition of dissolved matter in voids was also accounted for added mechanical strength. Strengthening was lastly believed to relate to a release of internal stresses by temporary softening the polymer. Thus it is believed that vapour polished FDM parts is a step closer to precision manufacturing.

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