# Effect of section thickness and build orientation on tensile properties and material characteristics of Laser Sintered nylon-12 parts

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## Abstract

It has been suggested that different section thicknesses in Laser Sintered parts may cause variations in mechanical properties, and this has previously been demonstrated for some properties (e.g. fracture toughness). The research presented here investigates whether the same is true of tensile properties, and whether the orientation of parts within the build volume has any effect on this. Results are presented for three different orientations of tensile specimens, at a range of thicknesses from 2mm to 6mm, showing that, at any of the orientations tested, the section thickness had no significant effect on any of the main tensile properties.

These results are in direct contradiction with related research investigating the effect of section thickness on Fracture Toughness, where an increase in thickness also increased the toughness of the parts. This highlights the importance to Additive Manufacturing users of identifying the correct properties to assess when choosing a suitable process or material, and when designing complex parts.

## Introduction

### Context

Whilst Additive Manufacturing (AM) technologies have to an extent become accepted by industry, their uptake has been slower than could be expected, largely due to a lack of knowledge regarding how to design for the relevant processes, and how components will behave in practice. Datasheet values of properties go some way to improving this situation, but are often regarded as providing insufficient information for ‘real life’ use. In addition, a substantial amount of anecdotal evidence is common within the AM community, much of which is either not fully accessible, or has not yet been proven.

In order for current and potential users of AM to take full advantage of the many benefits of these technologies, more information must be obtained, and published, regarding the use, and expected behaviour, of parts produced using various AM technologies.

The research presented here was performed as part of the £350,000 ‘Advanced Understanding and Control of Polymer Sintering’ (AUCPS) project, funded by Loughborough University’s Innovative Manufacturing and Construction Research Centre (IMCRC)[1], and in collaboration with Electro Optical Systems (EOS GmbH)[2], Burton Snowboards[3], and The University of Louisville[4].

Whilst many acknowledge the wide range of benefits offered by AM technologies, and in particular Laser Sintering (LS), and while there has been a considerable amount of published literature in these areas, many of the nuances of the LS process are still not fully understood.

The overall aim of the project is to achieve a greater understanding of the factors affecting the properties of polymer Laser Sintered parts, and in turn to use this understanding to control the behaviour of these parts, and to provide AM users and designers with the knowledge to achieve suitable performance from parts and components.

## Effect of geometry

Substantial amounts of research have been carried out into benchmarking of geometric capabilities for most AM systems, in terms of feature size resolution, surface finish and accuracy[5,6]. Additionally, a large amount of published data can be found relating to the effects of varying processing parameters on the mechanical properties that can be achieved[7,8,9].

However, little investigation has been made into the effects of geometry on the mechanical properties of the parts themselves. Datasheet values for many commonly required properties are quoted by many manufacturers, but only for standard specimen sizes. It has been suggested that, due to different thermal conditions when building parts of varying section thicknesses, the achievable properties may be markedly different. In order to gain increased acceptance, and uptake, of Laser Sintering, it is crucial to improve knowledge of the differences, if any, to be expected throughout a component featuring different cross-sectional areas.

## Related research – Fracture Toughness

Previous research within the AUCPS project has investigated the effect of section thickness on Fracture Toughness[10]. Laser Sintered single edge notch bending (SENB) beam specimens were produced at a range of thicknesses (2 mm to 10 mm), and showed an increase (~48 %) in the energy required to initiate crack growth per unit area with increasing thickness for LS Nylon-12 samples.

Laser Sintered samples produced at a range of thicknesses showed a small increase (~5 %) in density when increasing thickness of specimens from 2 mm to 10 mm, possibly due to improved heat retention in the thicker specimens, leading to an increase in the effective melt temperature, and subsequently to improved melt flow, and therefore to more effective sintering. A slight increase in crystallinity was also observed as section thickness increased.

However, these small increases in density and crystallinity were not considered high enough to cause the large increase in toughness observed, and it was suggested that increases in molecular weight in thicker specimens, due to increased time at elevated temperatures, could be the reason for these differences.

## Methodology

To complement the Fracture Toughness investigations described in the previous section, and as tensile properties are among the most commonly quoted for LS Nylon-12 parts, the following package of work was designed to assess the effects of section thickness on tensile properties. Tensile specimens were produced and tested at a range of thicknesses. Three different orientations were also assessed, in order to establish whether this in any way accentuated any effects of section thickness.

## Part geometry

Tensile test specimens were designed in accordance with BS EN ISO 527-2:1996[11], as shown in Figure 1.

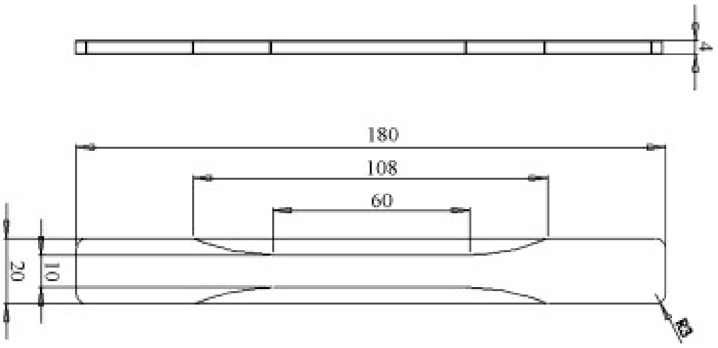

**Figure 1 - Tensile test specimen (all dimensions in mm)**

## Build layout

Tensile test specimens were produced at six different nominal thicknesses (2mm, 3mm, 4mm, 5mm and 6mm) and in three different orientations – YX, YZ and ZY (where the first letter denotes the axis parallel to the longest dimension, and the second letter denotes the axis parallel to the second longest dimension).

Six parts were produced at each thickness and each orientation, five of these for tensile testing, and a further sample of each for any additional material testing required at a later date.

Figure 2 shows the layout of parts within the build volume.

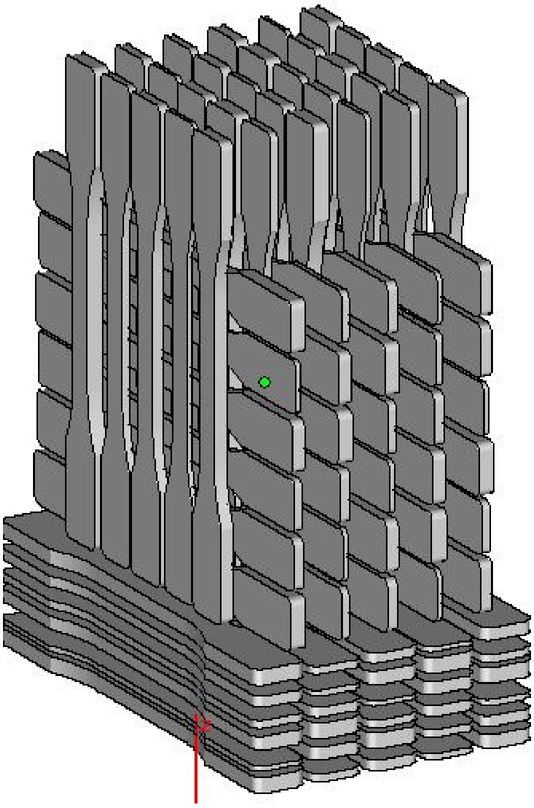

**Figure 2 - Build Layout**

## Laser Sintering parameters

Parts were produced in PA2200 (a Nylon-12 based polymer provided by EOS), on an EOS Formiga P100 system. All parts were produced using the manufacturer's default processing parameters for this material, as shown in Table 1.

| Parameter | Setpoint |
|---|---|
| Layer thickness | 0.1mm |
| Part bed temperature | 172 °C |
| Removal chamber temperature | 159 °C |
| Laser power (contour) | 16 W |
| Scan speed (contour) | 1500 $mms^{-1}$ |
| Laser power (hatching) | 21W |
| Scan speed (hatching) | 2500 $mms^{-1}$ |
| Scan spacing | 0.25 mm |
| Pre-heat time | 2 hours |

**Table 1 - LS processing parameters**

Once building was complete the parts were left to cool to 50°C before removing from the part cake.

### Tensile testing

All specimens were conditioned at 20 °C (+/−1 °C) and 50% (+/−5%) relative humidity prior to testing. Tensile tests were performed on the specimens using a Zwick Z030 tensile testing machine fitted with a long travel contact extensometer. The Young's Modulus was measured using a 1mm/min strain rate to 0.25 %, following which the Tensile Strength and Elongation at Break were measured at 5mm/min until failure of the specimen. The Zwick software, TestXpert, was used to enable the calculation of the Tensile Strength, Young's Modulus and Elongation at Break of each of the parts.

## Results

### Specimen thickness

During testing it was noted that in every case the actual measured thickness of the specimens was somewhat larger than the nominal value, suggesting that the scaling factors set within the P100 operating software require adjustment. This was true to the greatest extent when producing parts in the YX orientation, whereby the actual thickness was on average 9.8% larger than the nominal value, as compared with an average of 3.5% larger in YZ and ZY.

However, as the calculated values for tensile properties, presented in the following sections, take into account the actual thickness of the specimen, these differences between actual and nominal dimensions will not affect the results shown.

### Tensile Strength

Figure 3 shows the Tensile Strength for each of the thicknesses and orientations tested.

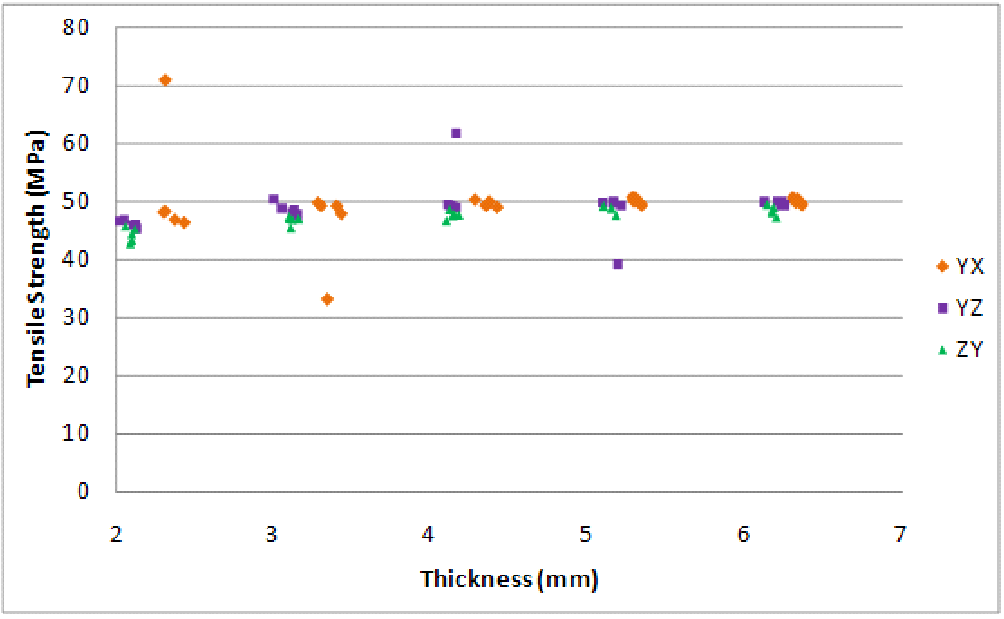

**Figure 3 - Tensile Strength at different thicknesses and orientations**

It can be seen from Figure 3 that, within the range tested, there is no obvious effect of section thickness on Tensile Strength at any of the orientations tested.

In order to further assess any relationship between the section thickness and Tensile Strength, the Coefficient of Determination ($R^2$) value was calculated for each orientation (see Table 2 for values). A linear regression analysis indicated a slight increase in Tensile Strength with increasing thickness, but it can be seen that all values of $R^2$ fall well below the value of 0.9 generally accepted as indicating a strong correlation, confirming that there is no significant effect of section thickness on Tensile Strength.

| Orientation | $R^2$ |
|---|---|
| YX | 0.00 |
| YZ | 0.06 |
| ZY | 0.65 |

**Table 2 - $R^2$ values for correlation between thickness and Tensile Strength**

Figure 4 shows the effect of orientation on Tensile Strength. All specimens produced in each orientation were averaged and included here.

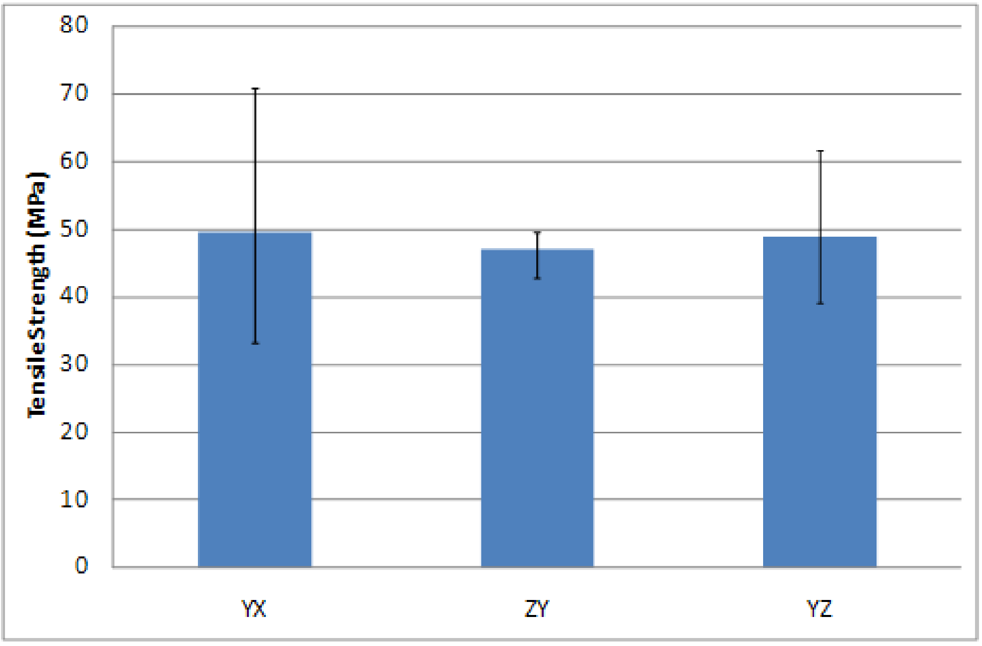

**Figure 4 - Effect of orientation on Tensile Strength**

The results shown in Figure 4 demonstrate that the orientation of parts had no apparent effect on the Tensile Strength. The large range in results for the YX and YZ conditions can be explained by two anomalous values for each condition, and therefore is considered random rather than of any significance.

## Young's Modulus

Figure 5 shows the Young's Modulus for each of the thicknesses and orientations tested.

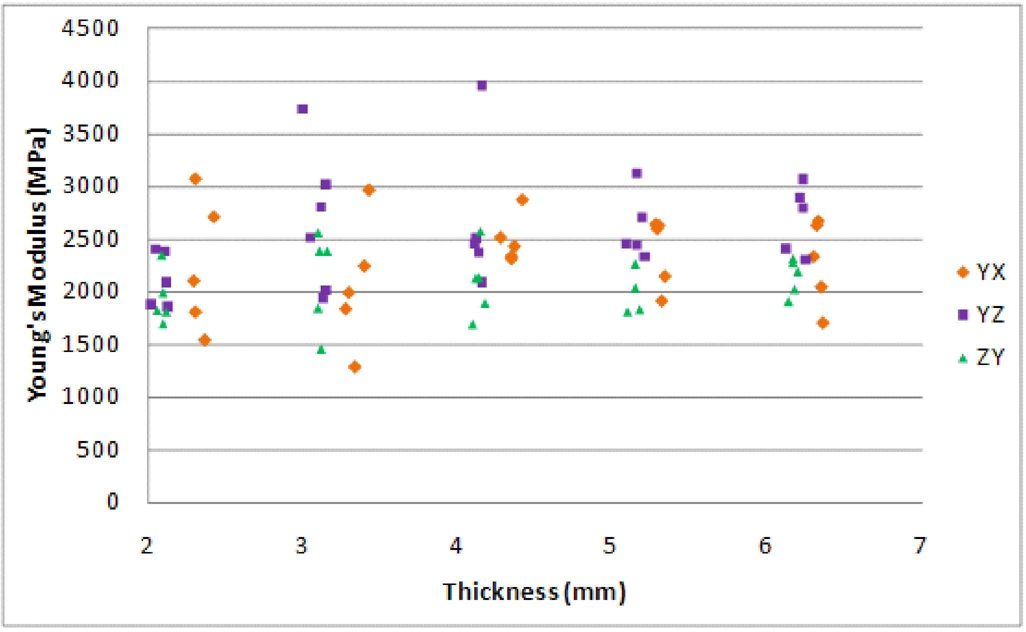

**Figure 5 - Young's Modulus at different thicknesses and orientations**

The results show in Figure 5 indicate that, again within the range tested, there is no obvious effect of section thickness on Young's Modulus at any of the orientations tested.

Table 3 shows the R2 values generated for each orientation, and it can be seen that all values of were less than 0.1, further confirming the lack of any relationship between section thickness and Young's Modulus.

| Orientation | $R^2$ |
|---|---|
| YX | 0.02 |
| YZ | 0.08 |
| ZY | 0.02 |

**Table 3 - $R^2$ values for correlation between thickness and Young's Modulus**

Figure 6 shows the effect of orientation on Young's Modulus.

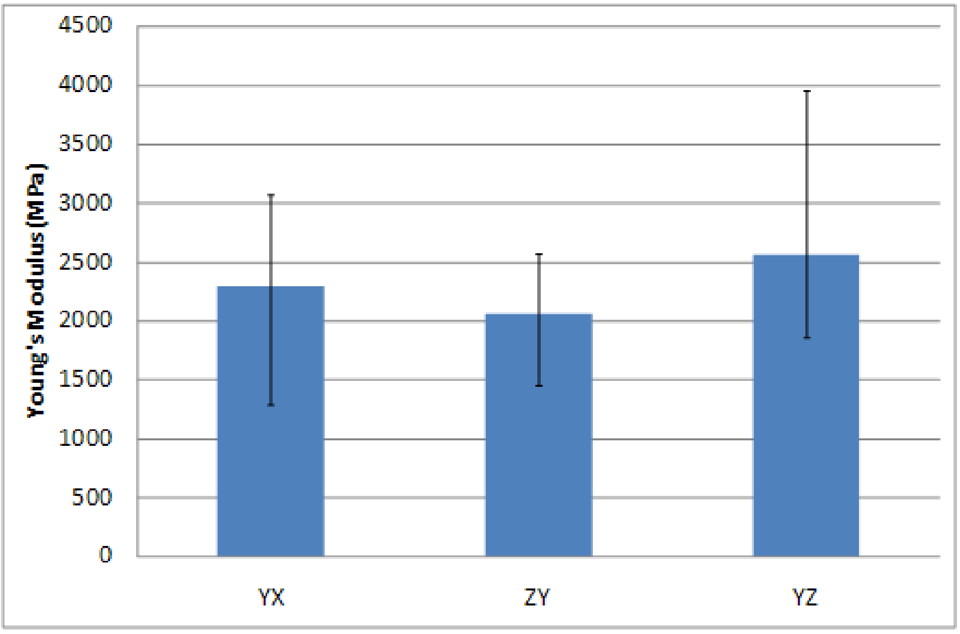

**Figure 6 - Effect of orientation on Young's Modulus**

It can be seen from Figure 6 that, as with Tensile Strength, part orientation had no significant influence on the overall values recorded. Whilst the values recorded for the YZ direction show a small increase in the average value, the wide range of results for each condition, and the large overlap in range, means that no clear statement of effect can be made.

## Elongation at Break

Figure 7 shows the Elongation at Break for each of the thicknesses and orientations tested.

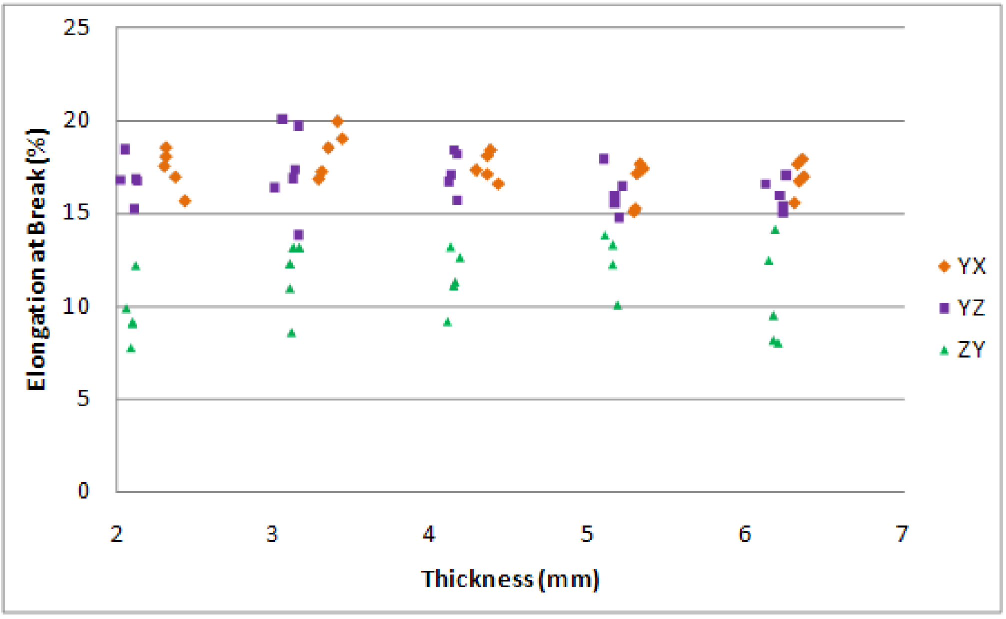

**Figure 7 - Elongation at Break at different thicknesses and orientations**

As with the Tensile Strength and Young's Modulus, it can be seen that there is no apparent influence of section thickness on Elongation at Break.

Table 4 shows the $R^2$ values obtained for each orientation. It can be seen that for every orientation the $R^2$ value is 0.10 or less, once again confirming that there is no significant effect of section thickness on this property.

| Orientation | $R^2$ |
|---|---|
| YX | 0.10 |
| YZ | 0.09 |
| ZY | 0.03 |

**Table 4 - $R^2$ values for correlation between thickness and Elongation at Break**

Figure 8 shows the effect of orientation on Elongation at Break.

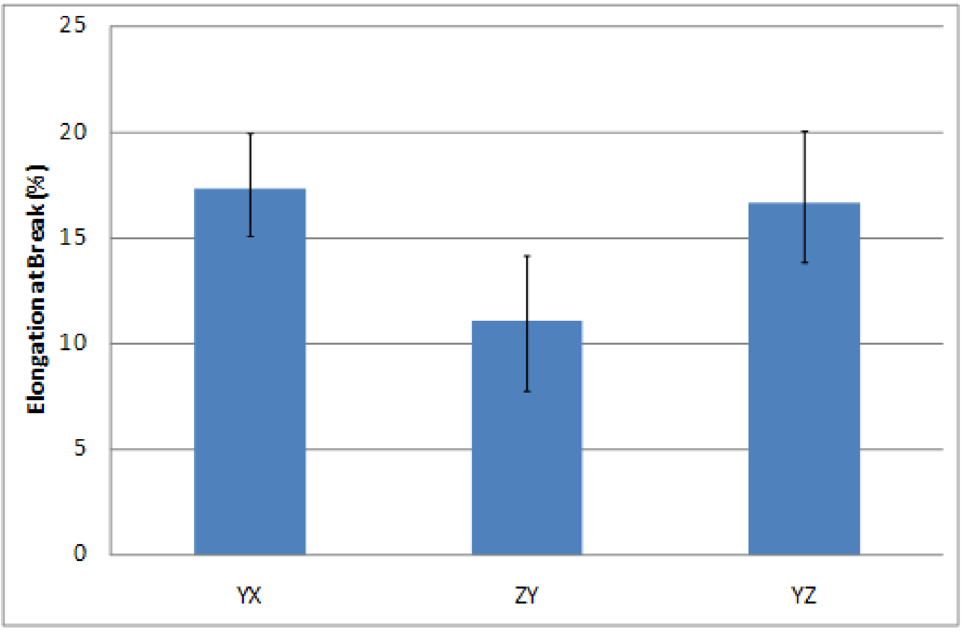

**Figure 8 - Effect of orientation on Elongation at Break**

In this case, as would be expected based on previous research[12], the samples produced in the ZY orientation showed a lower average Elongation at Break (~ 0.65 that of the YX and YX orientations). The range of results achieved was relatively constant across all three conditions.

**Discussion and Conclusions**

When considering Tensile Strength and Young's Modulus, the orientation of the parts showed no demonstrable effect on the values achieved, demonstrating that they are more robust to changes in build layout. The same was true for the Elongation at Break in the YX and YZ direction, with a decrease in the property when parts were produced in the ZY direction. Results also show that, within the range tested, section thickness has no significant effect on tensile properties at any of the orientations tested, in contradiction with the effects previously identified for Fracture Toughness.

This would indicate that the small increases in density and crystallinity previously reported at larger section thicknesses are not large enough to have a significant effect on tensile props. Although not yet confirmed, the expected increase in molecular weight caused by the higher time at elevated temperature for thicker cross-sections, appears to also have no significant effect on tensile properties. These results indicate that the Fracture Toughness is substantially more susceptible to variations in these properties than the Tensile Properties of LS parts.

Additional research within the AUCPS project[13] has since demonstrated a decrease in molecular weight between LS parts produced early in a build and those produced closer to the end of the same build. This clearly adds weight to the argument that increased time at elevated temperature causes an increase in the molecular weight of parts. Further work is planned to investigate the suggestion that thicker parts do indeed possess higher molecular weight, and also that it is this difference in molecular weight that causes the variations in Fracture Toughness. The inclusion of additional tensile test specimens within this work will also enable confirmation (or otherwise) that the tensile properties are substantially less susceptible to changes in molecular weight than the Fracture Toughness.

In terms of practical implications of this research, the results presented indicate that the tensile properties of LS Nylon-12 parts are particularly robust to changes in geometry and or orientation, providing AM users with a high level of freedom over their designs. The one exception is when considering Elongation at Break, where care must be taken to avoid orientating in the Z direction if the highest properties are to be achieved.

Finally, the research presented here, and the different trends seen for different mechanical properties, has highlighted the importance for AM users of clearly identifying the most crucial properties to identify for their required application.

**Acknowledgements**

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