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INVESTIGATIONS FOR THE OPTIMIZATION OF VISUAL AND GEOMETRICAL PROPERTIES OF ARBURG PLASTIC FREEFORMING COMPONENTS

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Abstract

Arburg Plastic Freeforming (APF) is an additive manufacturing process with which three-dimensional, thermoplastic components can be produced layer by layer. Visual and geometrical properties are a major criterion for characterizing the resulting component quality. The aim of this study was to investigate the influences on visual and geometrical properties of APF components depending on process parameters. Initially the focus was on the analysis of the shrinkage behavior of ABS-M30 (Stratasys). On the basis of the results and an existing procedure by the machine manufacturer, an optimized procedure for determining the scaling factors was developed to counteract the shrinkage. With this procedure a higher dimensional accuracy of the components can be achieved. In addition, it was investigated whether an adaption of the form factor based on a mathematical model depending on the component geometry makes sense. The results were transferred into manufacturing guidelines, which allow the user of the APF-technology to optimize process parameters more efficiently.

Introduction

The Arburg Plastic Freeforming (APF) is a relatively new additive manufacturing process with its official presentation in 2013. With this process it is possible to manufacture three-dimensional components using standard granulates without the need of molding tools using the Freeformer machine system [1]. The unique technique of the material deposition in the APF process is opening a new field of possibilities and also new boundary conditions. E.g. the shrinkage behavior of components manufactured with the APF differs from other additive manufacturing processes.

The aim of this research is the determination of parameter-dependent influencing factors on the manufacturing process and the resulting geometrical and visual component properties. This includes the investigation of the shrinkage behavior. An optimized methodology for the determination of the scaling factors for the shrinkage compensation is derived from the results. Last, a look is taken at the influence of the form factor on the visual properties of components based on their geometry. All investigations are carried out using ABS-M30 filament (Stratasys) which was shredded to allow the processing of the material in the APF process.

State of the Art

The Arburg Plastic Freeforming is characterized in particular by the processing of standard plastic granulates as well as by the production of components out of very fine molten thermoplastic droplets. The associated machine system for this technology is the Freeformer from Arburg GmbH & Co KG. Its most important machine components are shown in Figure 1. The raw material, a qualified standard thermoplastic granulate, is fed via a hopper. In the material preparation unit, the granulate is molten with a screw as in the injection molding process. The molten material is then pressed into the material reservoir. Here, a piezo actuator performs a pulsed nozzle closure using a needle to close the nozzle opening. The needle in the nozzle moves up and down, producing almost 250 droplets per second. The movement of the building platform, for the precise positioning of the discharged droplets in the x- and y-direction, is realized by two linear motors. After the completion of a layer the building platform is lowered by one-layer thickness, using a spindle drive [1, 2, 3].

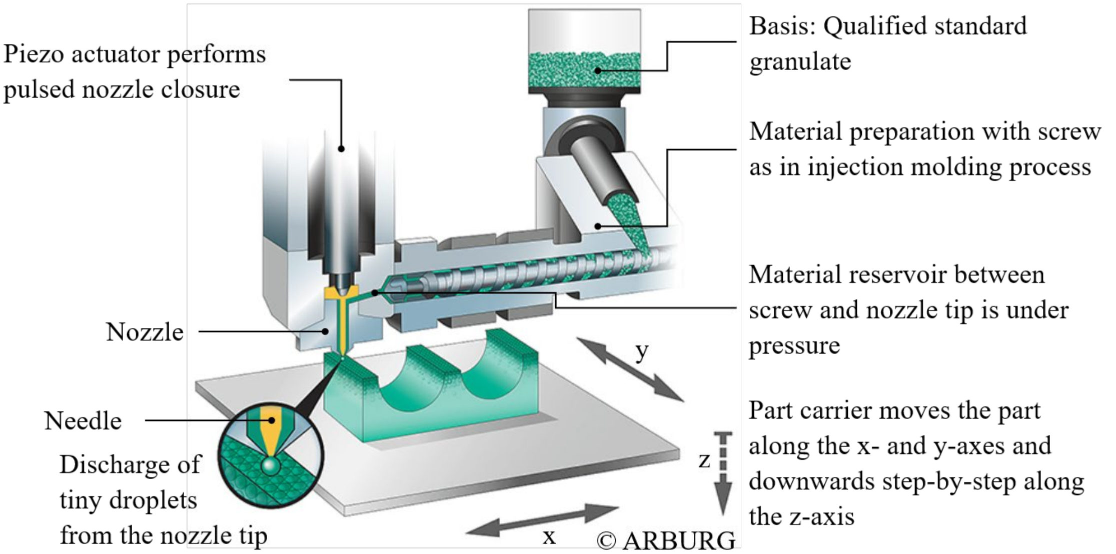

Figure 1: Schematic setup of the Freeformer [1].

One of the most important process parameters with an influence on the component geometry is the form factor. It is a special process parameter for the plastic freeforming. The form factor is used to set the distance between the single droplets and between the droplet chains (Figure 2 a) [4]. Consequently, this parameter influences the porosity and filling of the components. Figure 2 b) shows the influence of the form factor on the surface quality. The left figure shows an overfilled component with an uneven surface. The illustration on the right shows an ideal surface with the individual droplets of a not overfilled test specimen. Based on such an analysis of the surface, a simplified visual determination of the form factor is carried out. This must be done with every new material, in order to process it with the Freeformer.

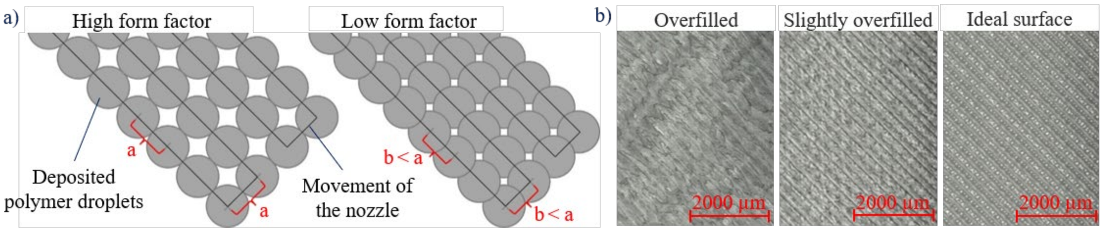

Figure 2: a) Schematic description of the process parameter form factor [4], b) Evaluation of the component surface of overfilled and non-overfilled test specimens.

Shrinkage of thermoplastic polymers is among other things influenced by material accumulations, the complexity and orientation of the component and the used parameter-set. An uneven distribution of wall thicknesses leads to a non-uniform cooling. A non-uniform cooling entails an irregular shrinkage which finally leads to warpage and geometrical deviations [5], [6], [7]. For the determination of the shrinkage of a specific material, specimens are built and measured. The discrepancy between the nominal and the measured value is calculated. To calculate the shrinkage in percent (scaling factor) the value of the discrepancy is divided by the nominal length and multiplied with the factor 100 [8]. The shrinkage is compensated by stretching the part virtually in all directions with regard to the determined scaling factors [9]. In Figure 2 a build job for the scaling factor determination is shown as it is proposed by Arburg.

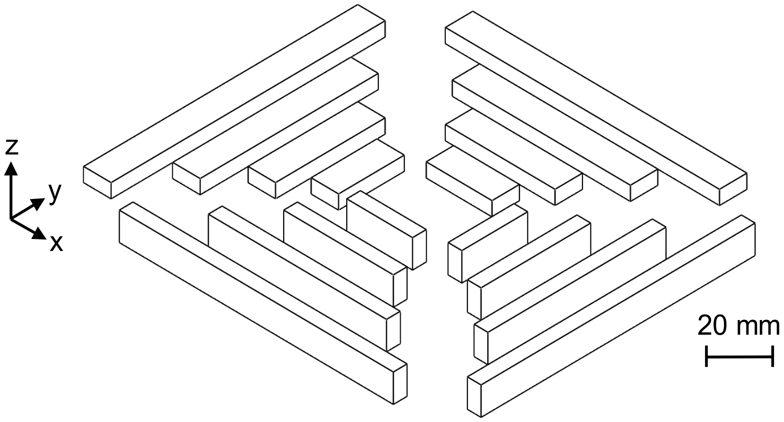

Figure 3: Build job for the determination of the scaling factors as proposed by Arburg [10].

Experimental Investigations

Prior to the investigations the scaling factors x: 1.0051 / y: 1.0048 / z: 0.9978 are determined using the build job shown in Figure 3. If not otherwise specified, these scaling factors are applied to all specimens during the entire investigations presented in this paper.

For the investigation of the deviations for linear component specimen geometries according to the nominal dimension classes of the DIN EN ISO 286-1 are selected. These cover the range between 3 mm and 120 mm with the steps 10, 18, 30, 50 and 80 mm in between. The quadratic cross section has a constant edge length of 10 mm. To level possible temperature effects, the positions of the specimens on the build platform are rotated for each job (see Figure 3). To evaluate the deviation both in the x- and the y-direction the specimens are rotated 90° around the z axis for individual build jobs.

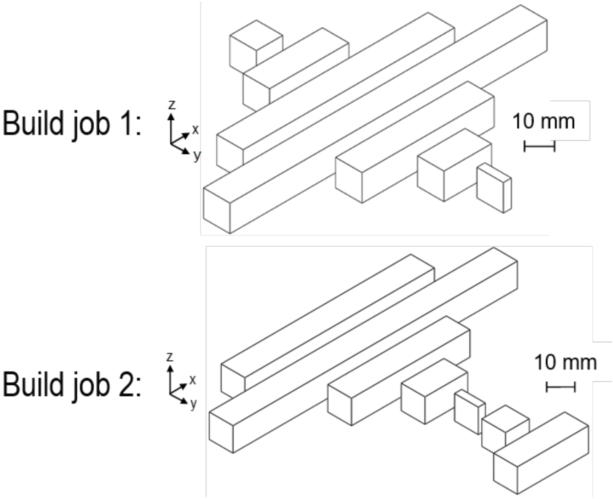

Figure 4: Exemplary visualization of a specimen rotation.

For the investigation of the deviation in the z-direction identical lengths and cross sections of the specimens orientated in z-direction are used. Due to an occurring oscillation of the specimens which leads to deviations of the measurements that are not solely influenced by the shrinking of the specimens, a supporting structure is designed and applied to the components (Figure 4). These supporting structures are manufactured with model material and are not removed for the measurement of the specimen height. The column in the center of the build job is used to position the nozzle there while waiting for the set minimum layer time to be reached when building only the last several specimen heights.

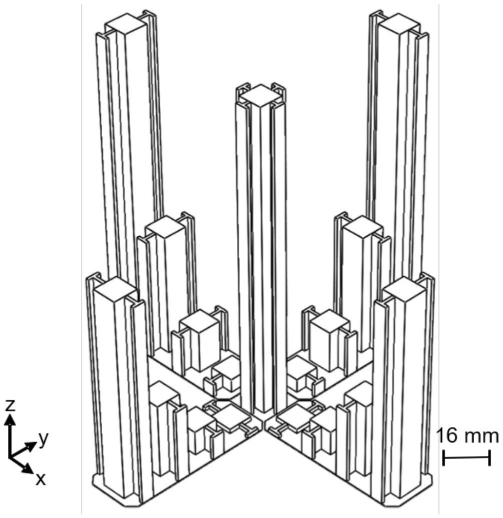

Figure 5: Depiction of the upright specimens for the investigation of the shrinkage in z-direction with the applied supporting structures.

After the manufacturing of the specimens the length of each specimen in its build orientation is measured. The measurements are conducted with an outside micrometer according to DIN 863-1.

Another aspect of the investigations is the possibility to adapt the form factor to specific component geometries using a mathematical model. For this, the background of the deposition of the drops is analyzed and transferred into a model which is evaluated afterwards.

Results and Discussion

All specimens' nominal lengths in their specific build orientation are measured as previously described. The results of the measurements are shown in Figure 6. The results show an approximately parallel progression of the values along the x- and y-axis. The specimens with a nominal length of 3 mm show a deviation of -0.017 mm along the x-axis. Along the y-axis no deviation is measurable. Overall the deviation increases with an increasing nominal length of the specimens. It is noticeable that the deviation along the y-axis, except for the nominal length of 3 mm, is slightly higher than along the x-axis. A reason for this might be the positioning accuracy of the axes which move the build platform in the process. As a shorter axis is used for the movement in the y-direction compared to the axis used for the movement in the x-direction, the axes are not identical. This might lead to a difference in the positioning accuracy and therefore to the different deviations in the x- and y-direction.

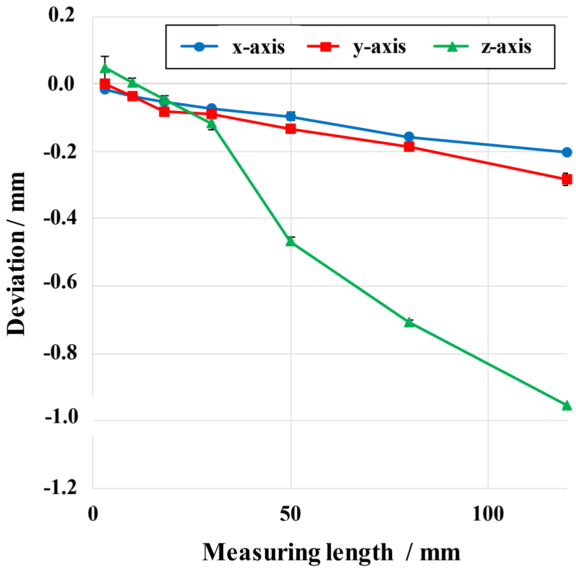

Figure 6: Results of the measurements of the specimens' nominal lengths.

The measurements of the nominal lengths in z-direction show great deviations. For the nominal lengths of 3, 10, 18 and 30 mm the deviation is in the same range as for the specimens orientated in x- and y- direction. All measurements are within the tolerance of the tolerance class IT12 according to DIN EN ISO 286-1. As shown in Figure 6 the deviation from the nominal length of 50 mm of the specimens orientated in z-direction is significantly higher compared to the values of the x- and y-direction. Especially the steeper gradient of the values between 30 and 50 mm is noticeable. The background of this phenomenon is that in this process a continuous scaling of the components in z-direction is not possible. Depending of the resulting component height after scaling either a layer is added on top or not. The context is presented in Table 1.

Table 1: Influence of the scaling factor on the number of layers in context with the component height.

Nominal length / mm	Number of layers (before scaling)	Scaling factor	Nominal length including scaling /mm	Number of layers (after scaling)	Number of layers (after scaling and rounding)	Discrepancy in layers
3	15	0.9978	2.99	14.97	15	0
10	50		9.98	49.89	50	0
18	90		17.96	89.80	90	0
30	150		29.93	149.67	150	0
50	250		49.89	249.45	249	-1
80	400		79.82	399.12	399	-1
120	600		119.74	598.68	599	-1

As shown in Table 1 due to rounding the number of layers after scaling for the lengths greater than 30 mm is lower by one. This leads to the steeper gradient between the measured deviations of the 30 and 50 mm nominal length specimens. If the missing layer is compensated by applying a scaling factor of 1.0000 for the z-direction the increase of the deviations in z-direction with increasing nominal length shows a nearly linear progression (see Figure 7).

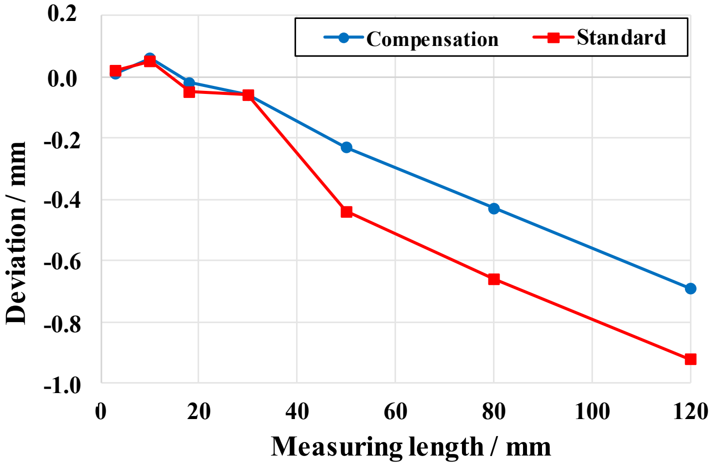

Figure 7: Influence of the scaling factor on the number of layers and thereby on the deviation in z-direction.

The build job used so far to determine the shrinkage and the corresponding scaling factors shown in Figure 3 shows some disadvantages. Small nominal lengths are not represented. The variation of the specimen length in z-direction is insufficient as there are only two steps with only a small difference. Also, different cross sections are not represented as the specimens are only tilted to the other side. Therefore, two sperate build jobs are developed. One for the x- and y- direction (see Figure 8) and the other for the z-direction (see Figure 5). They expand the range of the evaluated points and enable a more profound determination of the scaling factors.

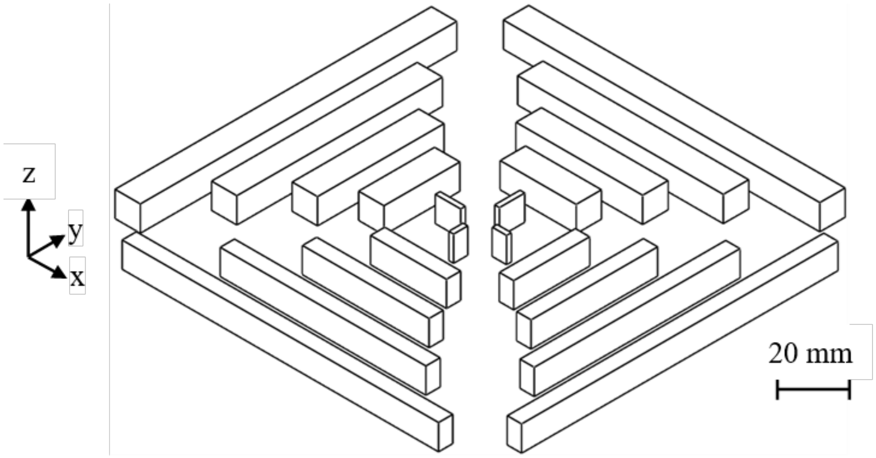

Figure 8: Improved build job for the determination of scaling factors in the APF process for the xy-direction.

Afterwards the influence of the form factor on the filling of components with different geometries is analyzed. For this, specimens with different wall thicknesses are built. All specimens have a length of 60 mm and a height of 4 mm. The wall thickness is differed in the steps 2, 4, 6, 8, 10, 15 and 20 mm. For each specimen the optimal form factor is determined through experimental investigations. The specimens are rated through the evaluation of the surface quality (under-/ overfilled) and the dimensional accuracy. The results show differences in the considered criterions. But in the follow-up of the investigations it was found that the different form factors considered did not result in a change of the building process. Therefore, all detected differences are process fluctuations.

Based on the findings a mathematical model is developed to precisely determine the so-called critical length of a part. That is the length the part has to have for the machine to be able to fill without leaving a gap or overfilling the part as only full drops can be deposited. As this only is viable for integer multiples of the critical length, this method is hardly implementable for components containing more than one wall thickness. Especially if the raster angle and other process parameters are considered, which also have an influence of the resulting critical length.

Conclusion and Outlook

In this paper the evaluation of the dimensional accuracy of linear elements with applied scaling factors, which were previously determined, was evaluated. The results show that for the x- and y-direction the deviation of the elements fulfills the requirements for the tolerance class IT12 according to DIN EN ISO 286-1. In z-direction an unfavorable scaling leads to the omission of single layers which again leads to higher deviations. Based on the findings two new build jobs were designed to evolve the build job which is suggested for the determination of the scaling factors.

An investigation of the influence the form factor has on the filling of components was conducted. In the course of the investigations it was shown that a small variation of the form factor in theory has no influence on the filling. Differences in the filling are solely caused due to process fluctuations. A mathematical model was developed to determine the critical length of a component in which no gaps are left during filling and no overfilling occurs. It shows that it is possible to precisely adapt the form factor to a specific component length. In a complex component, all lengths must be integer multiples of the critical length which is difficult to realize in the practical application.

In the future, more detailed investigations will be carried out to determine not only influences of the process parameters on the dimensional accuracy but also machine specific influences. In addition, the dimensional accuracy of more complex geometries will be investigated.

Acknowledgement

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