Dimensional Tolerances for Additive Manufacturing (DT-AM)

Technical parts are designed computer-aided at its theoretical ideal shape. However, manufacturing always leads to geometrical deviations. The functionality of technical parts in terms of its assembling ability is significantly influenced by the interaction of various geometrical deviations. For this reason, it is essential that the geometric shapes meet their requirements. Thus, limits need to be given for the geometrical deviations that is typically done by tolerances. For additive manufacturing, it is currently unknown how large such tolerances have to be. Thus, no reliable and comprehensive information about tolerances for additive manufacturing are defined in standards.

1. Objectives

The project "Dimensional Tolerances for Additive Manufacturing" has two different objectives.

1 Objective: Dimensional tolerances are systematically determined that can be stated if additive manufacturing is used under normal workshop conditions. Normal workshop conditions describe the application of often used and established standard parameters, materials and machine settings.

2 Objective: Relevant process parameters and manufacturing influences are investigated in order to define measures that minimize dimensional deviations.

2. Procedure

WP1 & 2: Within the first step of the project, two methods are developed. The first method describes a proceeding for the examination of dimensional deviations that can be used to derive realistic tolerance values. The second method describes a proceeding for the reduction of dimensional deviations by the identification and optimization of process parameters and manufacturing influences. **WP3 & 4:** Within the second step, experimental tests are performed to investigate occurring dimensional deviations. Parallel, optimized settings for process parameters and manufacturing influences are identified in order to reduce dimensional deviations. **WP5 & 6:** Within the third step, dimensional tolerances will be derived from the measured dimensional deviations. Furthermore, measures will be derived in terms of guidelines that can be used to reduce dimensional deviations. **WP7:** In the end, the results will be analyzed and interpreted.

3. Latest results

Based on the developed method, the experimental tests were extended for the processes laser melting, laser sintering and Fused Deposition Modeling. Besides the external dimension also internal dimension were investigated in the last year. The nominal dimension of the test specimen was manufactured up to the maximum of each machine envelope. Additionally, the nominal dimensions were aligned along the x, y and z axes (Figure 10). After the manufacturing, the test specimen were measured with a defined measurement method to identify the occurring dimensional deviations.

Figure 11 shows the detected dimensional deviations for external dimensions that were manufactured with Fused Deposition Modeling. Within the diagram, the minima, maxima and mean values for the dimensional deviations (vertical axis) for each

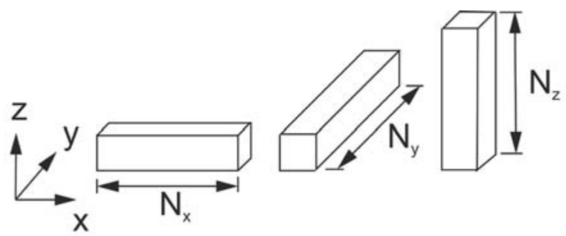

Figure 10: Test specimen for external dimensions aligned along the x, y and z axes

alignment (x, y, and z) are represented depending on the nominal dimensions (horizontal axis). The diagram emphasizes that the alignment and nominal dimension show a major impact on the dimensional deviations. For the x alignment, a positive increase of the mean values appears dependent on the nominal dimension, while for the y alignment the averaged deviations negatively increase.

The mean value of deviations range between +0.03 mm and +0.50 mm in the x alignment and between +0.06 mm and -0.30 mm in the y alignment. In the z alignment, alternating mean values are indicated between +0.12 mm and +0.47 mm. The alternating distance between averaged values compared to the x and y alignment is caused by the approximation of nominal dimensions through layers along the z-axis. Nominal dimensions, which are an integer multiple of layers, show a better dimensional accuracy in the building direction. In order to establish tolerances for additive manufacturing processes, the occurring deviations were classified in the ISO tolerance system according to DIN EN ISO 286-1. The derived tolerances between the minimum and maximum of deviations for Fused Deposition Modeling achieve IT classes between IT09 and IT14 for the external dimension. Further investigations showed that the different deviations in x, y, and z alignment were mainly caused by material shrinkage and other process parameters.

For the minimization of dimensional deviations, process parameters and manufacturing influences were investigated experimentally. The experimental studies of process factors demonstrated that dimensional deviations could be reduced significant by an optimal selection of parameter settings.

4. Outlook

The project is finished in the end of 2016 and was focused on dimensional tolerances. The next experimental test will deal with the examination of form and location tolerances. Therefore, an extension of the methodical approach is necessary in order to cover all geometrical deviations. Based on defined influential factors on the geometrical accuracy, new test specimens combined with suitable measurement methods will be developed.

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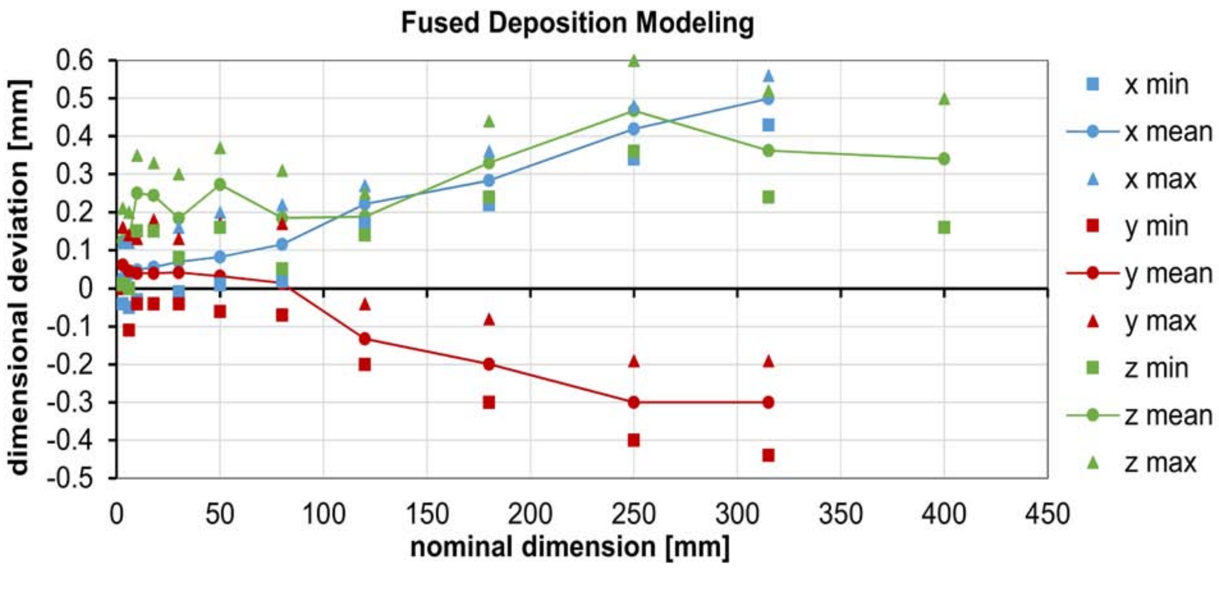

Figure 11: Maxima, minima and mean values of the occuring dimensional deviations for different nominal dimensions and alignments (x,y,z)