INFLUENCE OF SURFACE ROUGHNESS ON ADDITIVELY MANUFACTURED ALUMINUM COMPONENTS

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1. Introduction

Additive manufacturing (AM), in particular selective laser melting, is increasingly gaining importance in fabrication of complex components. A benefit of AM is the possibility to manufacture topologically optimized, lightweight parts [1]. However, a mechanical surface treatment of these complex structures is only possible to a limit extent or even not at all. A rough, non-machined surface acts like micro notches and influences the fatigue strength of AM components [2].

To assess the fatigue strength of parts with rough surfaces, standardized methods applying reduction factors, for example in the FKM guideline [3], exist. Mostly, these reduction factors are only applicable for directed and machined structures and within these concepts, only line-based surface parameters, according DIN EN ISO 4287, are included.

The aim of this research work is the assessment of as-built surfaces on the fatigue strength of AM aluminum components. In addition, area-based roughness parameters, according to DIN EN ISO 25178, are determined and applied for an advanced assessment of surface roughness effects on the fatigue strength.

2. Surface characterization

For the characterization of the unprocessed (as-built) surface and the determination of characteristic roughness parameters, the surface topography of each specimen was scanned with a digital light microscope. The scanned surface topography was subsequently processed by a user defined evaluation routine. Furthermore, the captured surface profile was filtered into a roughness and a waviness profile using a second-order robust Gaussian regression filter. The obtained areal roughness map was utilized to determine characteristic roughness parameters, which describes the as-built surface, see Fig. 1. The area-based arithmetic mean roughness S_a for the unprocessed surface is evaluated to 11.5 µm and the line-based arithmetic mean roughness R_a to 10.9 µm.

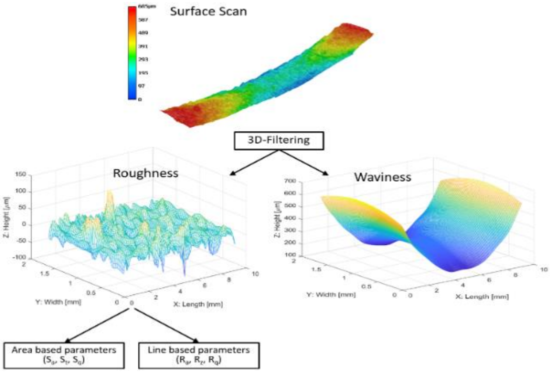

Fig. 1. Evaluation of surface parameters.

3. Experimental Results

The fatigue tests were performed under tension/compression at a load stress ratio of R= -1. One test series exhibits a machined, polished surface condition (P-AB) and a second batch features the unprocessed surface condition (UP-AB). The specimens were not heat treated. In Fig. 2. the results of the fatigue tests are shown. The results revealed a reduction in fatigue strength by 65%, comparing the rough specimen (b) to the machined test series (a).

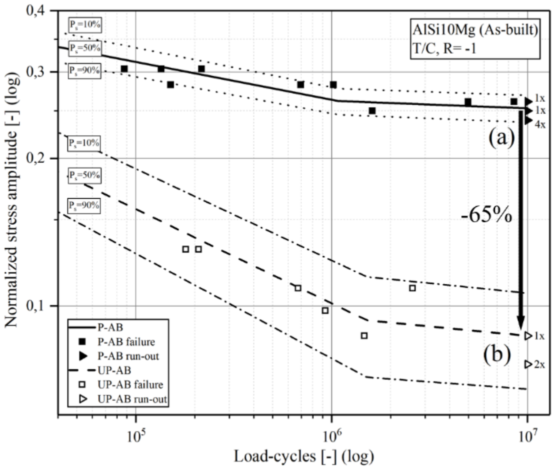

Fig. 2. Normalized S/N curves.

In Table 1. the fatigue strength (normalized to the nominal ultimate tensile strength of the base material) for a survival probability of 50% and the slope in the finite region is tabulated.

Table 1. High cycle fatigue test results.

Test-series	Surface condition	Normalized fatigue strength	Finite slope k_1
P-AB	Machined	0.253	13.0
UP-AB	As-built	0.087	5.2

To characterize the failure origin, an extensive fracture surface analysis was carried out for every tested specimen using a digital light microscope. In Fig. 3. the fractured surfaces of two specimens are illustrated. Within the fracture surface analysis, two different failure mechanism were observed. In case of the specimens with polished surfaces, the crack initiated from surface near pores (a). For the unprocessed surface condition, the failure originated from roughness valleys (b).

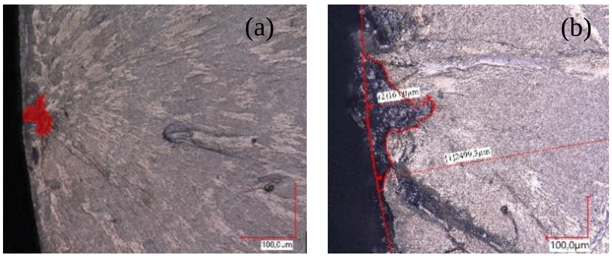

Fig. 3. Microscopic images of two characteristic defects

4. Assessment of surface effect on fatigue

For the assessment of the surface roughness effect on the fatigue strength, a model based on a stress concentration factor, according to a concept of Peterson, see Eq. (1), was applied [4]. Whereby, t stands for the notch depth and r is the notch root radius.

$$K_t = 1 + 2\sqrt{\frac{t}{r}} \tag{1}$$

To estimate the reduction of the fatigue strength in case of a rough surface, the notch depth t was calculated as the mean value of the area-based maximum surface deviation S_t. The average notch ground radius r was measured in longitudinal direction of the scanned surfaces. In Table 2. the evaluated values for the analytical approach and the resulting stress concentration factor K_t are given. To facilitate a conservative approach, the support effect was not accounted for and the stress concentration factor K_t was equated to the notch factor K_f.

Table 2. Values for analytical estimation of K_t.

Test-series	Mean notch radius r	Notch depth t	K_t
UP-AB	197.6 μm	167.1 μm	2.86

The reduced fatigue strength $\sigma_{D,rough}$ of the unprocessed surface condition was estimated by dividing the experimental fatigue strength $\sigma_{D,polished}$ of the polished specimen, by the stress concentration factor K_t due to of the rough surface. A comparison of the estimated reduced fatigue strength $\sigma_{D,rough}$ with the experimentally determined fatigue strength $\sigma_{D,rough,exp}$ shows a sound correlation, see Table 3.

Table 3. Comparison of fatigue strength values.

$\sigma_{D,polished}$	K_t	$\sigma_{D,rough}$	$\sigma_{D,rough,exp}$	Deviation
0.253	2.86	0.089	0.087	+2.3%

Conclusions

Due to the micro notch effect of rough surfaces, the fatigue strength is significantly reduced. The presented evaluation concept, applying a stress concentration factor according to Peterson, allows a good estimation of the fatigue strength of AM structures including the surface roughness effect. Future research activities will focus on the impact of residual stresses and the support effect in order to holistically characterize influencing factors on the fatigue strength of AM components.

Acknowledgements

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