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Precision finishing of additively manufactured components using the immersed tumbling process

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Abstract
Additive manufacturing enables the production of highly complex metallic components with highest geometrical flexibility in dedicated lightweight construction. For titanium-aluminium alloys, which are used in particular in the aviation industry, powder bed based processes such as the laser powder bed fusion are established. Nevertheless, laser powder bed fusion is limited with regard to the producible surface roughness in a range of 5 µm ≤ Ra ≤ 15 µm. According to the state of the art, the increase of the geometrical accuracy and the reduction of the surface roughness values of the additive manufactured components are realised by different cutting and non-conventional processes. In this investigation, a new approach for the reduction of the surface roughness values by immersed tumbling was realised. Therefore, additively manufactured square bars made of the titanium alloy Ti-5Al-5Mo-5V-3Cr were used as sample geometries. An immersed tumbling machine tool with planetary kinematics for post-processing was applied and the lapping media QZ, HSC 1/500 and M5/400 were evaluated. In addition, the influence of the rotor speed and the holder as well as the depth of immersion were considered as influencing factors. As target values the surface roughness values as well as the rounded edge radius were examined. Within this investigations the surface roughness values could be reduced by more than 90 %. In addition, a targeted rounding of the edges could be obtained, which removed the excess edge height at the part resulting from the laser powder bed fusion process. As a result the immersed tumbling process shows a great suitability as a finishing process for additively manufactured components and is particularly suitable for automated and serial finishing processes.

additive manufacturing, post processing, immersed tumbling process

1. Introduction

Additive Manufacturing technologies enable the production of components with highest geometrical flexibility in lightweight construction. However, the powder bed based processes are limited regarding the achievable surface roughness values in the range of 5 µm < Ra < 15 µm. Due to growing requirements concerning the process and the workpiece, new application areas could be obtained as well as innovative process chains need to be developed [1]. For Titanium-Aluminium(Ti-Al) alloys, the laser powder bed fusion process is established. At the state of the art, cutting and ablative processes are applied for the post-processing of these components [2]. These processes are often associated with increased effort. Due to thermal stresses, the generated geometry deviates strongly and the achievable geometrical accuracy a_g ist limited. A promising approach to precisely finish the additively manufactured parts is the immersed tumbling process. The components are moved through a loose abrasive lapping medium by means of a planetary gear. In this way, a material separation is achieved [3]. In the present study the suitability of the immersed tumbling process for the finishing of additively manufactured components made of a Ti-Al alloy was investigated.

2. Experimental setup

2.1. Lapping media selection

In this investigation the three different loose abrasive lapping media QZ, HSC 1/500 and M 5/400 which were provided by the company Otec Präzisionsfinish GmbH, Straubenhardt, Germany were examined. Detailed knowledge due to previous research works enabled a dedicated selection of the media for the investigations. The used lapping media are characterised by abrasive properties and different materials and grain sizes d_k, which enable a efficient process. In general, the coarse layers of the additively manufactured components were removed with subsequent finishing steps. The grain sizes d_K as well as the compositions of the lapping media are listed in Table 1.

Table 1. Visualisation of the used processing media

Media	Composition	Grain size of abrasive d_K
QZ	100 vol.-% aluminiumoxide	500 µm
HSC 1/500	95 vol.-% walnut granulate with 5 vol.-% silicon carbide	300 µm
M 5/400	99 vol.-% corn granulate with 1 vol.-% diamond powder	17 µm

2.2. Testing methods and devices

All experiments were carried out with square bar specimens with the dimensions 5 mm x 5 mm x 50 mm manufactured by the laser powder bed fusion process. The test samples were made of the Ti-Al alloy Ti5Al5Mo5V3Cr0.5Fe (Ti5553) with a maximum grain size d_{max} = 45 µm from the company Advanced Powders & Coatings, Québec, Canada, using the machine SLM 250 HL of the company SLM Solutions Group AG, Lübeck, Germany. To produce the sample geometries, a laser power P_L = 275 W, a scan speed v_S = 1.000 mm/s, a hatch distance h_S = 0,12 mm and a focus offset x_F = 0 mm were used. The post-processing was carried out on the immersed tumbling machine DF-3 Tools of the company Otec Präzisionsfinish GmbH, Straubenhardt, Germany. To evaluate the influence of the process parameters the rotor speed n_R, holder speed n_H, depth of immersion t_E and processing time t_P were investigated. The surface roughness characteristics was examined with the measuring device nanoscan 855 of the company JENOPTIK AG, Jena, Germany. To evaluate the edge height h_E, the component edges were analysed with the optical measurement device InfiniteFocus from the company ALICONA IMAGING GMBH, Graz, Austria.

3. Experimental investigations

The aim of the investigation was the development of a suitable process chain for the surface finishing of additively manufactured components made of the Ti-Al alloy Ti5553. Therefore, an analysis of the influence of the rotor speed n_R, holder speed n_H, depth of immersion t_E and processing time t_P was carried out. For this purpose, the sample geometries were initally machined with the coarse-grained lapping medium QZ due to the abrasive properties. After processing times of 5 min ≤ t_P ≤ 60 min the surface roughness characteristics were determined. The results are shown in Figure 1.

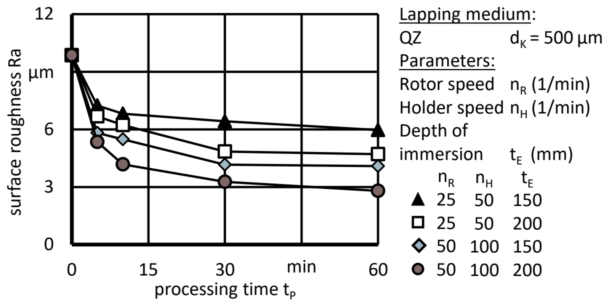

Figure 1. Surface rougness Ra in dependency of the processing time t_P

It could be figured out that the set of process parameter with a rotor speed n_R = 50 1/min, a holder speed n_H = 100 1/min and a depth of immersion t_E = 200 mm shows the greatest impact on the surface roughness Ra. In addition, it can be determined that the difference between the individual parameter sets increases with growing processing time t_P. Overall, in this first process step the surface roughness could be reduced from Ra = 9.83 µm to Ra = 2.80 µm. This represents an improvement of nearly 70 % for the evaluated roughing process.

To broader the range of application for additively manufactured parts, surface roughness values of Ra ≤ 1 µm need to be achieved. For the development of an efficient process chain for finishing additively manufactured components made of the Ti-Al alloy Ti5553, the influence of the two additional media HSC 1/500 and M 5/400 was evaluated. Based on the previuos investigations, the parameter set with a rotor speed n_R = 50 1/min, a holder speed n_H = 100 1/min and an depth of immersion t_E = 200 mm was used. The results of the subsequently and dedicated use of the three media within the immersed tumbling process of Ti5553 parts are shown in Figure 2.

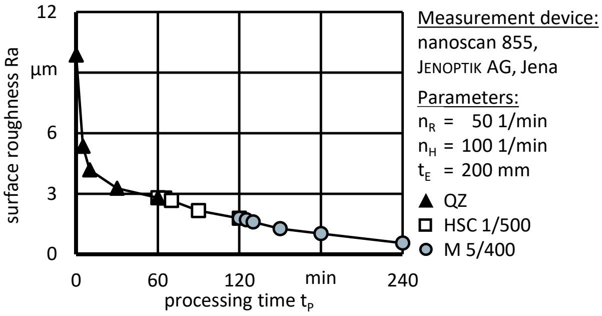

Figure 2. Surface rougness Ra in dependency of the processing time t_P

The results show that the surface roughness Ra could be strongly improved concerning the specific combination of the lapping media. The order of the media was chosen regarding to the abrasive properties. Using the lapping medium QZ led to a strong decrease of the surface roughness Ra up to a processing time of t_P = 30 min. Subsequently, a linear improvement of the surface roughness Ra could be obtained, caused by the initial state of the surface roughness value. The all-ceramic medium QZ strongly removes the roughness peaks, which leads to a fast improvement of the surface roughness Ra. After using the lapping media with reduced grain sizes d_k and a processing time of t_P = 240 min, the surface roughness could improved to Ra = 0.56 µm. This behaviour is primarily related to the decreasing abrasive grain size d_K and the increasing hardness H of the media. A further reduction of the surface roughness Ra could be achievable with higher process times t_P, but results in a more inefficient process.

The specific process conditions of the laser powder bed fusion leads to an elevation of the component edges, which represent a form deviation from the desired component geometry. Therefore, the edge height h_E of the components were examined to increase the optical und functional properties [3]. The results show that the edge height h_E could be reduced from h_E = 130 µm in the initial state to h_E = 57 µm after a processing time of t_P = 240 min using the lapping media M5/400. This represents a reduction of nearly 55 %. An exemplary component edge before (a) and after (b) the machining is illustrated in Figure 3.

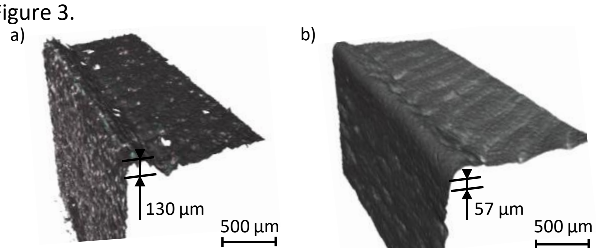

Figure 3. Component edge a) before and b) after the preparation

Despite the strong reduction of the edge height h_E, it is difficult to achieve a sharp edge geometry with the immersed tumbling process. Other limitations include the machining of external geometries as well as the containment of the lapping medium in internal geometries.

4. Conclusion

The findings show that a dedicated process chain composed of near net shape Additive Manufacturing and the immersed tumbling could be developed. Using a combination concerning different lapping media shows a suitable method for the surface finishing of additively manufactured components made of the Ti-Al alloy Ti5553, which improved the surface roughness to Ra = 94 % and enables the reduction of the edge height to h_E = 55 %. In addition, the used unbonded abrasive grains and the avoidance of adaptation to the component geometry enables a more efficient machining compared to conventional processes. Further investigations will address the use of modified immersed tumbling processes with a moving media.

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