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Integration of RFID tag in additive manufactured parts

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Additive Manufacturing, Influences, Readibility, RFID Integration, Ultra-High-Frequency

Abstract

This paper discusses the integration of on-metal tags in additively manufactured Ti-6Al-4V geometries. The manufactured components are to be equipped with information and read out due to aircraft maintenance work. Due to the complex installation and the mostly insufficient accessibility of the component in the installed state in the aircraft, a high read range and readability is mandatory. The integration involves ultra-high-frequency tags, which should promise a long range. The readability of the tags was therefore investigated in different open geometries. Here, some of the integrated tags were readable. In addition, tags were completely embedded in order to understand the effects in the component. The focus here was on the effects in the embedding chamber of the tag. Therefore, the fully embedded tags were cut open and examined. Some tags were readable, others were destroyed during the process. This was due, among other things, to the very hot environment of the process, as this depends highly on the actual permitted operating temperature of the tags. In addition, powder residues and adhesions were noted. These aspects are crucial for subsequent research involving the integration of tags.

1 Introduction

The additive manufacturing of metallic components has experienced a brisk upswing in recent years, particularly in the aerospace, automotive and medical technology sectors [1].Selective laser melting (SLM) is an additive manufacturing process from which metallic components are produced without the use of mold or tools. In this process, powder layers are applied to a build platform and melted with a laser. The molten layers fused with the underlying layers in a material-bonding process. This produces high material densities and near-net-shape geometries [2]. New possibilities arise in the production of aerospace-relevant components, especially the processing of titanium alloys. Due to their good strength, corrosion resistance and low weight, titanium alloys have become indispensable in aircraft construction. New technologies and the materials used in them must meet high safety standards before they can be certified by aviation authorities [3]. In order to comply with safety standards, component tracking is playing an increasingly important role in aerospace. The component and its entire product lifecycle from conception to recycling should be fully documented. To replace paper documentation and ensure the flow of information along the complete value chain, an innovative labeling system specifically for additively manufactured parts is being investigated. The integration of elements for data recording and the associated possibilities for storing, reading and tracking offer completely new application scenarios [4]. In the studies on tracking the life cycle, marginal conditions must be fulfilled e.g. high technical demands on storage and communication units, which must remain functional for the entire duration of an aircraft's life. The solutions are currently Radio-frequency Identification (RFID) integrated labels, which combine the clarity of a conventional nameplate with the functions of a digital marking solution. These labels electronically store information and are applied on components like from the A350 series aircraft but also for life jackets and seats [5]. The aviation industry specifies the requirements that a labeling solution must fulfill. For example, the maintenance information must be available and stored for at least 12 years after the first delivery of the component or passive RFID tags with EPC ("Electronic

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Product Code") [6]. Furthermore, more requirements, based on the aerospace industry, were considered. One requirement is the use of a passive RFID tag. Passive tags do not require an integrated energy source to read the signal. The reader provides the energy to read the information. This delivers power to the tag and allows it to communicate with the reader [5]. Another requirement is the use of a specific frequency of the tag. This shall be ultra-high frequency (UHF) range and is approximately between 860 and 960 MHz [7]. The advantages of UHF technology are primarily the long reading range, the bulk detection and the robustness of the tags compared to other solutions e. g. optical recognition to read out data (bar/QR codes). UHFs can be read over a distance of several meters, even with a large number of chips, in contrast of barcodes, they do not need to be cleared of dirt. They are therefore theoretically suitable as a logistical marking solution in a company [8]. Furthermore, it was important that the tag does not exceed a certain size. The size of about 5 mm turned out to be the target. This will guarantee that a tag can be integrated in smaller components. Table 1 shows an excerpt from this. Another decisive point in the selection of market-ready solutions was the readability in metallic environments. Reflective objects in the near of RFID antennas can reduce readout performance [9].

Table 1: RFID-Tag Samples and their properties

Common Properties	Product Name and specific Properties	Company
- Suitable for metallic environments - Passive UHF - Memory: 512 bit user memory - EPC standard	MAXDURA CERAMIC [10] - Size from ab 5x5x3 mm - Weight from 0.4 g - Material: Ceramic - Operating temperature: -40 °C to +85 °C - Storage temperature: -40 °C to +150 °C - Reading range: < 3 m	SMARTRAC
	SMART DOME FREESTYLE [11] - Size from 5x3 mm - Weight from 0.5 g - Material: Epoxy resin - Operating temperature: < 200 °C - Storage temperature: n. a. - Reading range: < 2 m	SMART-TEC

Radio waves from a reader excited to retrieve information. Through the EPC, the tags receive a uniquely assignable serial number, which is assigned once and contains specific product data. [12]. Additive manufacturing offers excellent opportunities for the integration of such systems in highly stressed components. In this paper, the challenges of integrating an RFID solution are discussed. Ti-6Al-4V specimens are created and RFID tags inserted. In addition to readability, the effects of integrating an RFID tag and the influence of the laser melting process on the tags will be investigated.

2 Materials and methods

2.1 Titanium alloy Ti-6Al-4V and selective lasermelting process

In this case, the aerospace-relevant titanium alloy Ti-6Al-4V from the fabricant AP&C is used for the integration of RFID tags. It is a spherical powder with a particle size distribution between 20 and 63 µm. [13] The composition can be found in Table 2. Ti-6Al-4V impresses with its outstanding properties. High strength up to about 1200 MPa and ductility up to 16 % with relatively low density of 4.43 g/cm³ find application in highly dynamic industrial areas. [14]

Table 2: Composition of Ti-6Al-4V powder [13]

Element	Al	V	O	Fe	C	N	Ti
Min.	5.5	3.5					Bal*
Max.	6.5	4.5	0.13	0.25	0.08	0.05	Bal*

*Bal = balanced

Ti-6Al-4V is assigned to α+β alloys [14]. Various elements stabilize the microstructure and shape the properties. In titanium, aluminum acts as an α-stabilizer and vanadium as a β-stabilizer [15]. Ti-6Al-4V can form different microstructures. However, this is strongly dependent on cooling rates as well as temperature levels and the associated diffusion processes [16]. In the SLM process, the microstructure segregates in lamellar form. This fine-pitched, martensitic microstructure is often called a "Widmanstätter" or "basket weave" microstructure [17]. Figure 1 shows a scanning electron image of an additively manufactured Ti-6Al-4V microstructure.

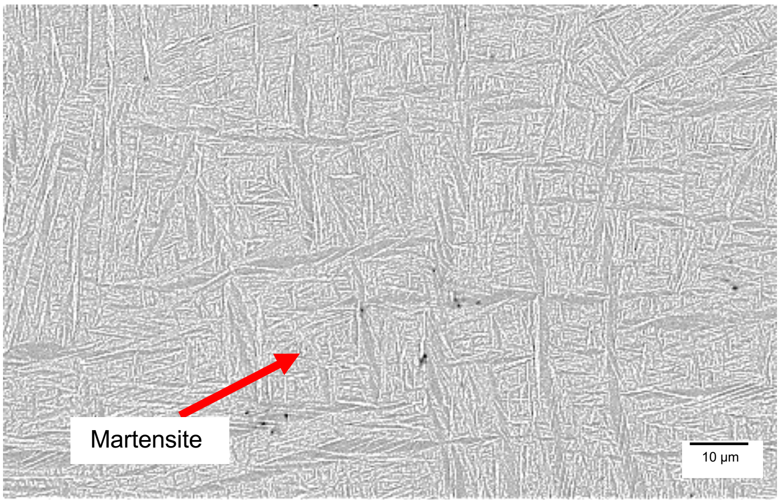

Figure 1: Image of an additive manufactured Ti-6Al-4V on Scanning Electron Microscope, due to high cooling rates the microstructure results in a fine-needled α-martensite [18]

The material was processed on the MTT SLM 250HL from SLM Solutions. The machine is a powder bed-based system (LPBF) that deposits powder in very thin layers on a substrate plate and melted by a laser according to data set. After this, a coater unit deposits a new layer of powder again and the melting process starts again. This cycle continues until the desired geometry has been produced. In order to keep oxidation of the powder as low as possible, the entire process takes place in a gas atmosphere [19]. Many parameters, which can have different influences on the material and the process, mark the process. Effects on component size, dimensional accuracy and density are possible. Therefore, it is mandatory to find the right parameters for the processing of certain materials in advance. This is also the case for Ti-6Al-4V. One parameter that clearly describes the processing of this material matched to the process is the volume energy density (E_V) or energy input per unit volume [20]. For Ti-6Al-4V, this is about 74 J/mm³ with the selected parameters.

2.2 Specimen preparation

The tags from SMARTRAC and SMART-TEC were put to an embedding test in a metallic environment for thermal resistance and readability. The test stand for readability involved two basic geometries (Figure 2) to a defined height from 1 to 6 mm and then inserting the RFID chip. This embedding geometry was referred to as "open". In the second test for thermal resistance, a tag was inserted and sealed during the process (Figure 3). Before the tags were integrated into the build process, their EPC number was read so that they could be uniquely identified during subsequent readout. The heights were from 1 mm to 4 mm from the component edge for the angular geometries and 1 mm, 3 mm and 6 mm for the round geometries (Figure 4). The angular geometries were examined first, from which the round geometries were examined based on the results.

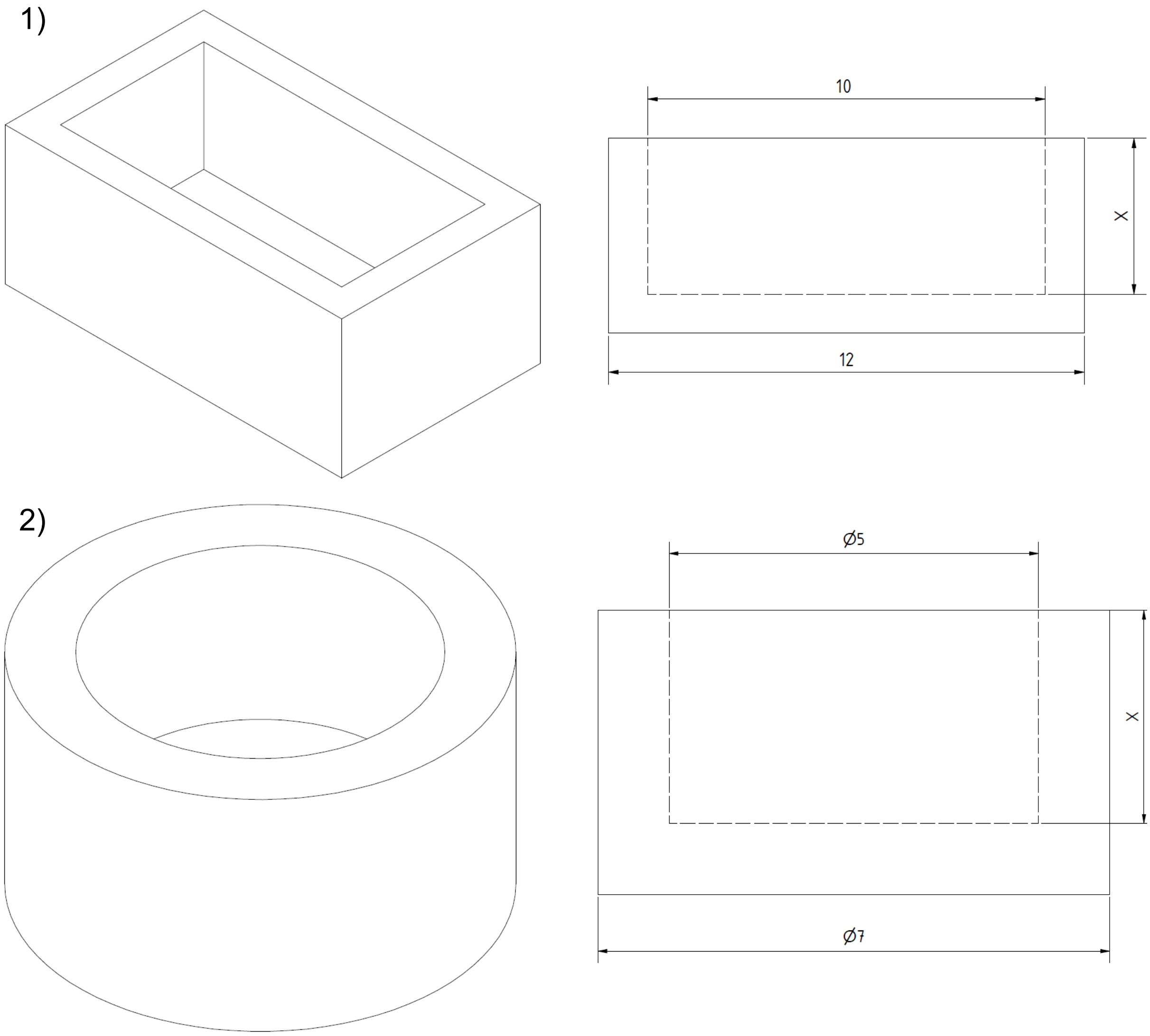

Figure 2: Geometry for embedding square tags (1) and round tags (2), "X" stands for the integration depth from 1 to 6 mm

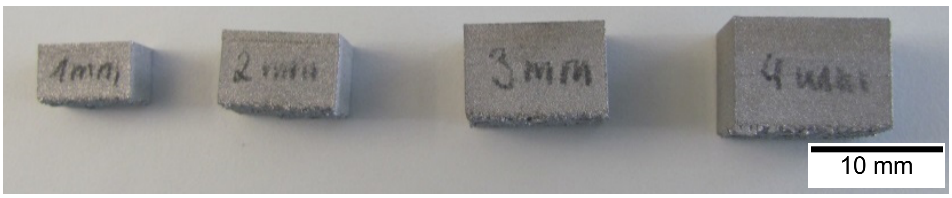

Figure 3: Fully embedded tags

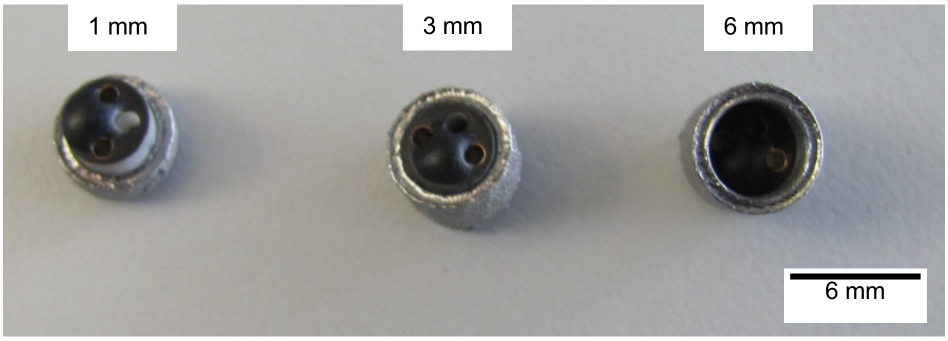

Figure 4: Round geometry for round tags with various depths

3 Results and discussion

A RFID handheld reader (model MC919ZEU from Symbol) checked the tags. The completely closed cube geometries as well as those with an open bed, but also the tag in the round geometry of 10 mm were not readable. They only formed reflections to other tags in the environment. The previous readout of the tags inferred this. The round geometries of 1 mm and 3 mm were only readable within a few centimeters of the reader. In summary, Table 3 shows the readability of the various embedded tags.

Table 3: Readability of the embedded tags

Tags	Readability
Fully embedded tags	No
Open	No
Round geometry	Yes: 1 mm and 3 mm depth
	No: 6 mm depth

In order to determine the thermal influence, the tags were opened from the completely embedded geometries. All tags which were inserted during the build process were not readable anymore. Some chips that had not been exposed to these high temperatures and had been inserted after the fact had the problem of not being readable. This was especially noticeable in the geometries that had a high tag insertion depth.

3.1 Thermal influence

Selective laser melting achieves a material bond not only by remelting the uppermost powder layer, but also the layers underneath [21]. A thin layer of powder over the RFID tag can therefore not stop the thermal influence and the resulting destruction of the tag. Figure 5 shows the different temperature influence in the powder bed through the powder adhesions and the annealing colors of the material. The RFID tag was located under this layer. When this chip was inserted into the still hot environment or surface of the geometry, the plastic layer also began to melt (Figure 6).

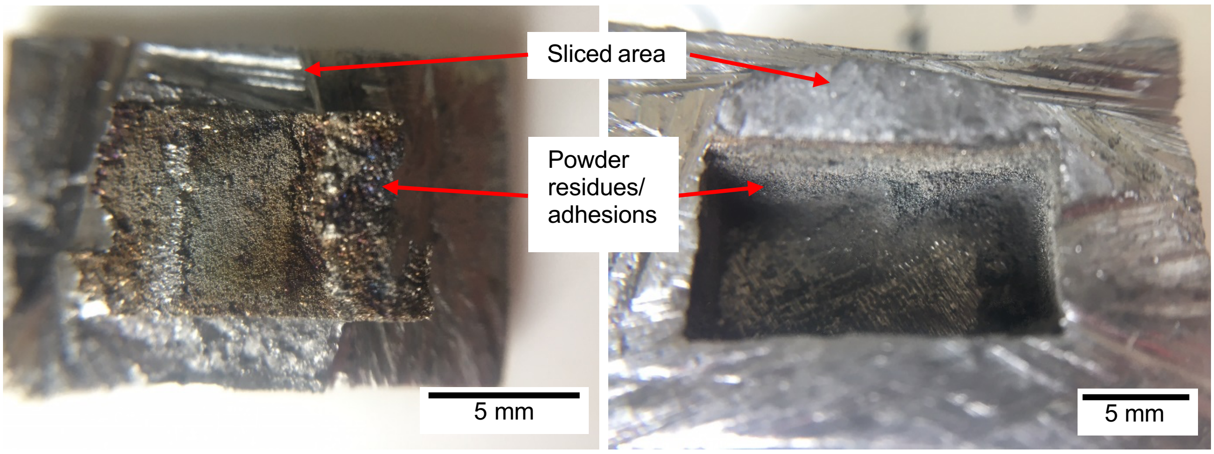

Figure 5: Cutted geometry with visible powder residues and adhesions (left: top party of geometry; right: bottom part of geometry)

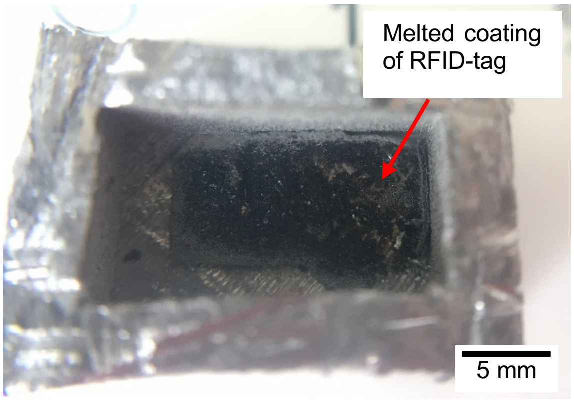

Figure 6: Melted plastic coating of the integrated RFID tag

3.2 Skin-effect

Electromagnetic signal shielding is generated when electromagnetic fields are enclosed or kept out by barriers. In addition to induced eddy currents, current displacement to the surface, the so-called "skin effect", also favors shielding. The skin effect results from the displacement of current toward the surface of the conductor. At high frequencies the current density of a conductor is no longer constant. This means that at the outer surface of the conductor the turbulences are smaller than in its volume. Therefore, the current flows along the outside. Based on this theory, the non-readability of the tags can also be concluded. Since the frequency range of UHF is in high-frequency range, the metallic layer that may lie over the tag must be therefore only have to be a few nanometers to micrometers thick to be able to read it out [22] [23] [24]. This is not possible in selective laser melting, since layer thicknesses of a few hundredths of a millimeter are only possible [25].

4 Conclusion

When integrating RFID tags, even if they should be suitable for the metallic environment, they have a low readability. The tag must not be embedded too deeply in the geometry, otherwise it cannot be read. The upper area of the tag must still be visible in order to ensure readability. Furthermore, the thermal influence must be taken into account when integrating tags during the manufacturing process. Tags made of plastic or plastic coating can be affected and destroyed. In addition, the embedding geometry must be further addressed in the future, since the consequences of the results shown here on high performance components cannot be estimated.

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References

[1] Industrieanzeiger: Generative Verfahren, Luftfahrt-Serienteile aus Metallpulver. https://industrieanzeiger.industrie.de/technik/entwicklung/luftfahrt-serienteile-aus-metallpulver/. (accessed 16 September 2021).

[2] Kroll, L. et. al.: Additive Layer Manufacturing Method for Producing a three-dimensional Object and three-dimensional Object. United States Patent Application Publication No. US 2014/0251481 A1, 2014.

[3] 3Druck.com: Premium AEROTEC bekommt Zulassung für additive gefertigte Titanbauteile in der Luftfahrt, 24.05.2019. https://3druck.com/case-studies/premium-aerotec-bekommt-zulassung-fuer-additiv-gefertigte-titanbauteile-in-der-luftfahrt-2882409/. (accessed 16 September 2021).

[4] Bundesministerium für Wirtschaft und Energie: Was ist Industrie 4.0?. https://www.plattform-i40.de/IP/Navigation/DE/Industrie40/WasIndustrie40/was-ist-industrie-40.html. (accessed 16 September 2021).

[5] Airbs S.A.S.: Airbus introduces hybrid “RFID integrated Nameplates” for tracing parts across all aircraft families, 01 May 2014. https://www.airbus.com/newsroom/news/en/2014/05/airbus-introduces-hybrid-rfid-integrated-nameplates-for-tracing-parts-across-all-aircraft-families.html. (accessed 16 September 2021).

[6] Wessel, R.: Airbus Issues RDID Requirements, Expands RFID Usage, 09 July 2009. https://www.rfidjournal.com/airbus-issues-rfid-requirements-expands-rfid-usage. (accessed 16 September 2021).

[7] Miller, J.: RFID-Frequenzen: niedrig, hoch und ultrahoch: Was steckt dahinter?, 03 October 2017. https://www.computype.com/de/blog/rfid-frequenzen-niedrig-hoch-und-ultrahoch-was-steckt-dahinter. (accessed 16 September 2021).

[8] Roedl, S.: UHF-Die Zukunftstechnologie für die Automobilproduktion?. https://www.innovating-automation.blog/uhf-automobil-produktion/?lang=de. (accessed 16 September 2021).

[9] Helmus, M; Becker-Meins, A.; Laußat, L.: Die Auto-ID-Technik der RFID. In: Kelm, A. (ed.): Integriertes Wertschöpfungsmodell mit RFID in der Bau- und Immobilienwirtschaft. Vieweg+Teubner, 2009.

[10] Smartrac: Maxdura Ceramic. https://rfid.averydennison.cn/content/dam/rfid/en/products/rfid-products/data-sheets/datasheet-Maxdura-Ceramic.pdf. (accessed 18 June 2018).

[11] Smart-Tex: RFID-/ NFC-Industrietransponder, 2021. https://www.smart-tec.com/de/produkte/rfid-nfc-industrietransponder. (accessed 18 June 2018).

[12] ECR Austria: Electronic Product Code (EPC). https://www.ecr.digital/book/gs1-standards/electronic-product-code-epc/. (accessed am 16 September 2021).

[13] AP&C: Ti-6Al-4V Grade 23 Powder, Material Certificate No MC-17-0673. Quebec, Kanada 2017.

[14] Wycisk, E.: Ermüdungseigenschaften der laseradditiv gefertigten Titanlegierung TiAl6V4. Springer Vieweg, 2017.

[15] Peters, M.; Leyens, C. (ed.): Titan und Titanlegierungen. Weihnheim: Wiley-VCH, 2022.

[16] Schulze, G.: Die Metallurgie des Schweißens. Berlin, Heidelberg: Springer, 2010.

[17] Siemers, C.: Metallografie von Titanlegierungen, Probenpräparation und Gefügeaufnahmen gängiger Titanwerkstoffe. Zürich: Olympia Verlag, 2013.

[18] Böttcher, K.; Winkler, K.: Microstructure Visibility of Additive Manufactured Ti-6Al-4V Geometries without Hydrofluoric Acid. In: Müller, B. (ed.): Fraunhofer Direct Digital Manufacturing Conference DDMC 2020. Berlin: Fraunhofer Verlag, 2020.

[19] Macherauch, E.; Zoch, H.-W.: Praktikum in Werkstoffkunde, 100 ausführliche Versuche aus wichtigen Gebeiten der Werkstofftechnik. Wiesbaden: Springer Fachmedien, 2019.

[20] Laserinstitut Hochschule Mittweida: Volumenenergiedichte Berechnung. http://www.laser.hs-mittweida.de/institut/projekte/height/teilprojekte/volumenenergie.html. (accessed 20 September 2021).

[21] Scharowsky, T.: Grundlagenuntersuchungen zum selektiven Elektronenstrahlschmelzen von TiAl6V4. Erlangen: FAU University Press, 2017.

[22] Spektrum: Elektromagnetische Abschirmung. https://www.spektrum.de/lexikon/physik/elektromagnetische-abschirmung/4046. (accessed 17 September 2021)

[23] Spektrum: Skin-Effekt. https://www.spektrum.de/lexikon/physik/skineffekt/13356. (accessed 17 September 2021).

[24] Heino, H.: Elektromagentische Felder, Theorie und Anwendung. Berlin: Springer Vieweg, 2020.

[25] Karlsruher Institut für Technologie: Schmelzvorgang beim selektiven Laserschmelzen. https://www.imvt.kit.edu/746.php. (accessed 17 September 2021).