

Article

Fracture Toughness of Ti6Al4V/Cp-Ti Multi-Material Produced via Selective Laser Melting

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Abstract: Multi-materials can locally enhance the properties of products to improve their performance. In some cases, it might be necessary to improve the fracture toughness properties locally. This work is devoted to investigating the fracture toughness of multi-material Ti6Al4V/Cp-Ti specimens produced via laser powder bed fusion (L-PBF). The powder feeding and distributing system of the L-PBF machine was modified for programmable dual-powder feed capability. The multi-material Ti6Al4V/Cp-Ti samples analyzed in this work are layered materials, where the Ti6Al4V alloy serves as the base material and Cp-Ti is present as separate layers. Samples of this type rely on the principle of crack inhibition, where fracture energy is dissipated in the more ductile Cp-Ti layers. Two variants of alternating ductile layers were studied. The microstructure of the materials and interfacial zone were analyzed using an optical microscope. Chemical composition was examined with a scanning electron microscope. The size of the interfacial zone in the multi-material averaged between 250 and 300 μm . A comparison of the tensile tests results with the literature data (of relatively pure Ti6Al4V alloy) reveals that there is a minor reduction in ultimate tensile strength and elongation. The obtained results confirm the possibility of locally increasing fracture toughness through the creation of a multi-material structure using L-PBF.



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Keywords: additive manufacturing; selective laser melting; multi-material; Ti6Al4V/Cp-Ti; fracture toughness

1. Introduction

Producing multi-materials by using several materials in one product can improve its performance due to the local increase in properties [1,2]. Multi-material products are used in various fields, like aerospace, energy, automotive, biomedicine, etc. [3]. There are various manufacturing technologies that are able to produce multi-materials, such as chemical vapor deposition, centrifugal casting, spark plasma sintering and others [4]. These technologies are well suited for producing parts with simple shapes or to make coatings, but their application is highly restricted. The use of additive manufacturing (AM) is promising for the production of multi-material products with complex shapes [5,6]. These technologies offer numerous advantages, such as significant freedom of design; increased production speed; decreased costs in small-scale production of complex-designed products; personalized production; reduction in the number of technological operations; shortened supply chains; and improved environmental friendliness of production [7].

Several types of AM can be utilized to produce multi-material products [8]. Direct energy deposition (DED) and powder bed fusion (PBF) are the most used processes for producing products from metal. The process of creating multi-material products using DED is relatively simple compared to PBF due to the utilization of multiple powder feeders and a fast production process [9]. However, DED has restrictions on the final dimensional accuracy of manufactured products [10]. Alternatively, the laser powder bed fusion (L-PBF) method can be used to produce products made of several materials with more

complex shapes and increased accuracy [11,12]. Several papers have demonstrated the rationale for the use of additive manufacturing in creating complex multi-material products. The importance of multi-material products has been noted, suggesting that such materials may better exploit the potential of additive manufacturing [13,14]. Products made of multi-materials have many potential applications: in the energy industry—heat exchangers; in the aerospace industry—combustion chambers of rocket engines; in the oil industry—gas burners, etc. [15,16]. Currently, there is active ongoing research on multi-material produced through L-PBF. One of the actively used alloys in this process is the titanium alpha-beta alloy—Ti6Al4V. Borisov E. V. et al. [17] studied the Ti6Al4V/Cp-Ti multi-material; the authors claimed that the multi-material products can be suitable for manufacturing of medical implants. In this type of multi-material, the Ti6Al4V alloy is responsible for providing strength to the products, while the Cp-Ti enhances corrosion resistance and plasticity [17]. The obtained samples were characterized by a clear transition zone that remained essentially unchanged upon heat treatment. The transition zone had a size of approximately 200 μm . The analysis of mechanical properties demonstrated that the position of the interfacial zone along the specimen has a greater impact on the mechanical properties than the shape and location of the dissimilar alloys. When the interfacial zone is located across the specimen, fracture takes place within the interfacial zone, resulting in a notably low level of elongation. Polozov et al. [18] investigated multi-material samples made of Ti6Al4V and a heat-resistant alloy Ti2AlNb. This multi-material has potential applications in the new generations of aircraft engines. While the Ti2AlNb intermetallic alloy can be used as a heat-resistant alloy at operating temperatures of 600–750 $^{\circ}\text{C}$, the Ti6Al4V alloy can be used at lower temperatures, resulting in decreased mass and improved fracture toughness. In the multi-material specimen containing Ti6Al4V and Ti2AlNb alloys, the interfacial zone displayed a distinctive microstructure with an inhomogeneous distribution of elements, while the width of the zone had a size of 100–150 μm . The heat resistance of the multi-material samples exceeded the pure Ti6Al4V alloy by approximately 35%.

Fracture toughness is a crucial property that ensures the durability of most products. L-PBF and DED parts exhibit considerably lower fracture toughness compared to parts produced conventionally [19]. Several research groups investigated this property for Ti6Al4V parts produced via L-PBF [20–22]. The authors observed the following general fracture toughness trends for this material. Samples after L-PBF without further heat treatment have reduced fracture toughness due to the presence of a brittle martensitic structure. After heat treatment, the fracture toughness characteristics are improved. Fracture toughness also varies with build orientation—horizontally grown specimens (where the crack propagates perpendicular to the build layers) exhibit better properties than vertically grown specimens (where the crack propagates parallel to the build layers).

Recently, several research groups have investigated the effect of heat treatment on the fracture toughness of products made from Ti6Al4V using the L-PBF method. Kumar P. et al. [23] studied the heat treatment impact on fracture toughness and crack growth resistance. A basket-weave microstructure is formed by a two-stage heat treatment at temperatures lower than the β -transformation temperature. After undergoing L-PBF, this heat treatment minimizes anisotropy, improves ductility and fracture toughness and decreases the fatigue crack growth rate. At the same time, the yield and tensile strength are reduced by approximately 20%. Jang H. et al. [24] concluded that the ductility of Ti6Al4V is significantly improved by heat treatment or hot isostatic pressing after L-PBF. The fracture toughness increased three-times, and the fatigue crack growth rate was the same as that of the traditionally produced Ti6Al4V. Surface machining led to a minor improvement in fracture toughness and fatigue crack growth rate. Other researchers conducted studies to investigate the impact toughness of multi-material Ti6Al4V/Cp-Ti specimens. Laser direct energy deposition (L-DED) technology was utilized by Turichin G. A. et al. to obtain a layered structure of Ti6Al4V alloy and Cp-Ti [25]. In this multi-material, the dissipation of fracture energy occurs as the crack crosses the interfacial zone due to the plasticity of

Cp-Ti layers, thereby improving the impact toughness. For multi-material samples, values of impact toughness were 2.5-times higher than those of pure Ti6Al4V alloy. In mechanical tests, intermediate strength and ductility values were observed in comparison to pure Ti6Al4V alloy and Cp-Ti.

Multi-materials can locally enhance properties to provide improved product performance. Recent research on multi-materials produced via L-PBF was briefly reviewed. It becomes evident that multi-materials containing Ti6Al4V alloy as one of their components have been widely studied. Researchers have investigated the structure, chemical and phase composition, as well as mechanical properties of these multi-materials. It is worth noting that the fracture toughness in this type of multi-material obtained via L-PBF has not been well explored, despite similar studies being carried out for other additive technologies and pure Ti6Al4V alloy. It has been observed that heat treatment can enhance the fracture toughness (while reducing the strength properties). However, it should be noted that this type of enhancement is applied uniformly throughout the entire product and prevents the local increase in properties. In some cases, it might be necessary to improve the fracture toughness properties locally, without decreasing the strength properties of the whole product [26]. Thus, this study aims to investigate the fracture toughness of multi-material Ti6Al4V/Cp-Ti samples, produced using L-PBF. Moreover, this work includes an investigation of the formed interfacial zone and mechanical properties.

2. Materials and Methods

2.1. Starting Materials and the L-PBF Process Parameters

Spherical powders of Ti6Al4V alloy (grade 5) and Cp-Ti (grade 2) were utilized to produce multi-material Ti6Al4V/Cp-Ti samples via L-PBF. Plasma atomization was employed to produce both powders (Normin LLC, Borovichi, Russia). The powders of Ti6Al4V alloy and Cp-Ti exhibited a spherical shape with a smooth surface and minimal number of satellites, as shown in Figure 1. The particle size distribution of the powders was analyzed using a laser diffraction particle sizer—Analysette 22 NanoTec plus (Fritsch GmbH, Idar-Oberstein, Germany). The particle size measurements were $d_{10} = 20.5 \mu\text{m}$, $d_{50} = 37.4 \mu\text{m}$, $d_{90} = 64.1 \mu\text{m}$ and $d_{10} = 19.7 \mu\text{m}$, $d_{50} = 35.9 \mu\text{m}$ and $d_{90} = 61.3 \mu\text{m}$ for Ti6Al4V alloy and Cp-Ti, respectively.

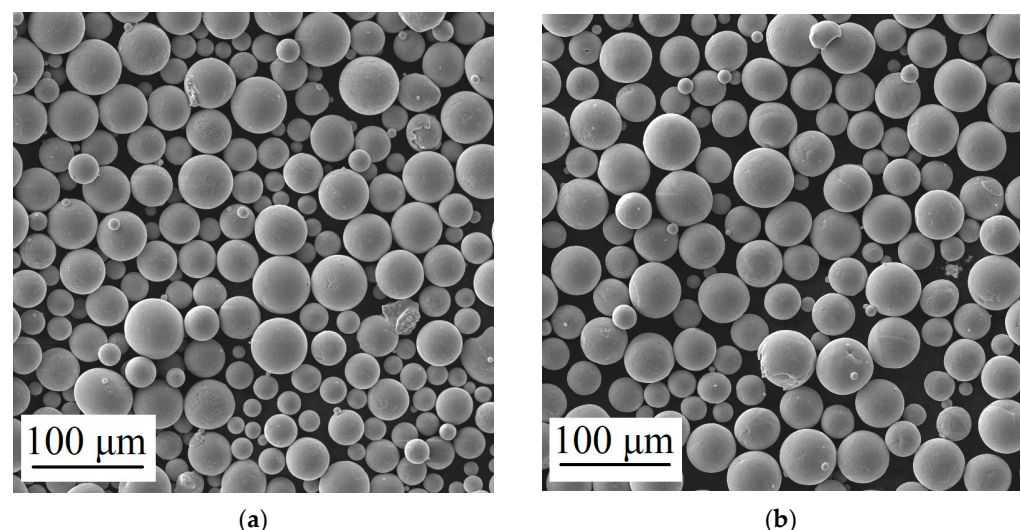


Figure 1. Morphology of (a) Ti6Al4V and (b) Cp-Ti powders.

Multi-material Ti6Al4V/Cp-Ti samples were manufactured using a 3DLam Mini L-PBF machine (3DLam, Saint Petersburg, Russia) under an Argon atmosphere on the titanium base plate. The original factory model of the machine underwent modifications to enable the creation of multi-material samples. The powder feeding and distributing system was

modified for programmable dual-powder feed capability during L-PBF. This system allows for the selection of which powder to apply on certain layers by using an additional powder hopper and dispenser. To print both Ti6Al4V alloy and Cp-Ti, identical parameters were used, as outlined in previous research: scanning speed of 805 mm/s, laser power of 275 W, hatch distance of 120 μm and layer thickness of 50 μm [17].

2.2. Multi-Material Ti6Al4V/Cp-Ti Samples for Tensile Test and Measurement of Fatigue Crack Growth Rate

Multi-material Ti6Al4V/Cp-Ti specimens obtained using the L-PBF method and used for tensile tests and fatigue crack growth rate measurements are shown in Figure 2. The multi-material Ti6Al4V/Cp-Ti samples are layered materials, where the Ti6Al4V alloy serves as the base material and Cp-Ti is present as layers. Samples of this type rely on the principle of crack inhibition, where fracture energy is dissipated in the more ductile Cp-Ti layers. Two variants of alternating ductile layers were studied—one with 600 μm ductile Cp-Ti and 1200 μm Ti6Al4V alloy, and another with 1050 μm ductile Cp-Ti and 2100 μm Ti6Al4V alloy. The first variant contained three layers of Cp-Ti (multi-material sample III—MMS-III), while the second variant had only two layers (MMS-II). Therefore, the total length of the alternating layers was 4.2 mm in both variants (as illustrated in Figure 2). The samples for tensile tests had the following geometric dimensions: a gage length of 20 mm and a gage width of 5 mm; a thickness of 2 mm; a grip section of 15 mm; and a grip section width of 8.2 mm. The fatigue crack growth test samples were made according to ASTM E647—15 with the following dimensions: $W = 25\text{ mm}$, $B = 6.25\text{ mm}$, $a_n = 4.55\text{ mm}$, $a = 5.15\text{ mm}$ and a distance from “ a ” to the beginning of Cp-Ti layers of 5.145 mm and 5.175 mm for MMS-III and MMS-II, respectively.

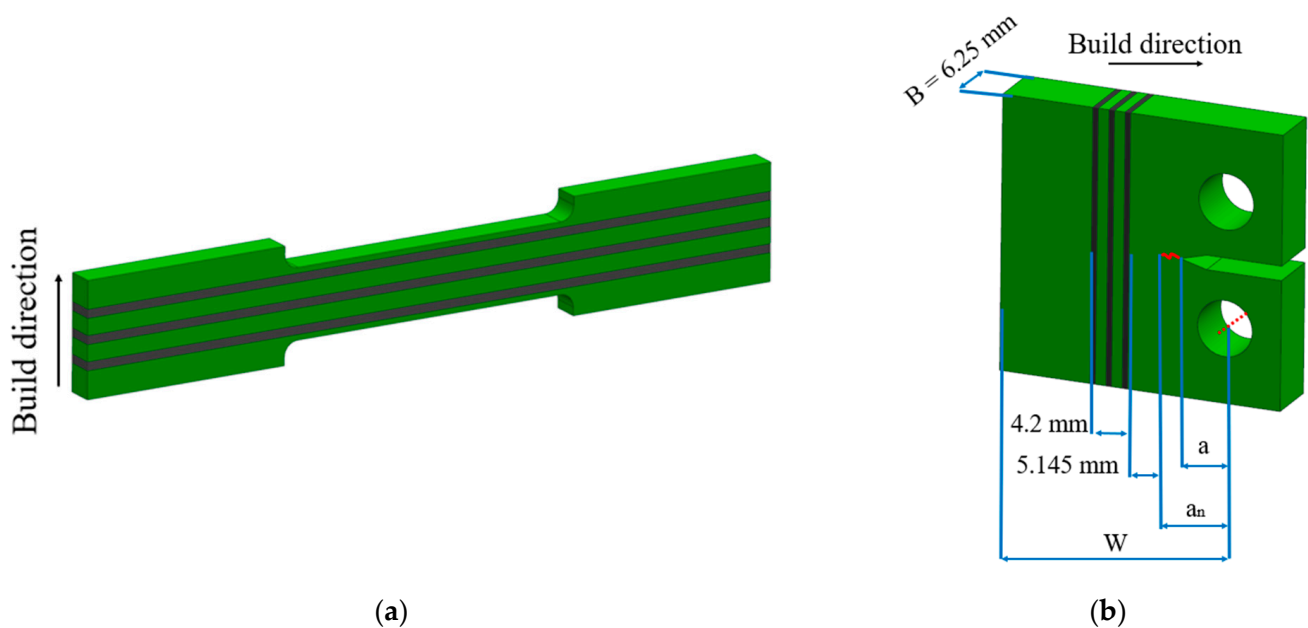


Figure 2. Cont.

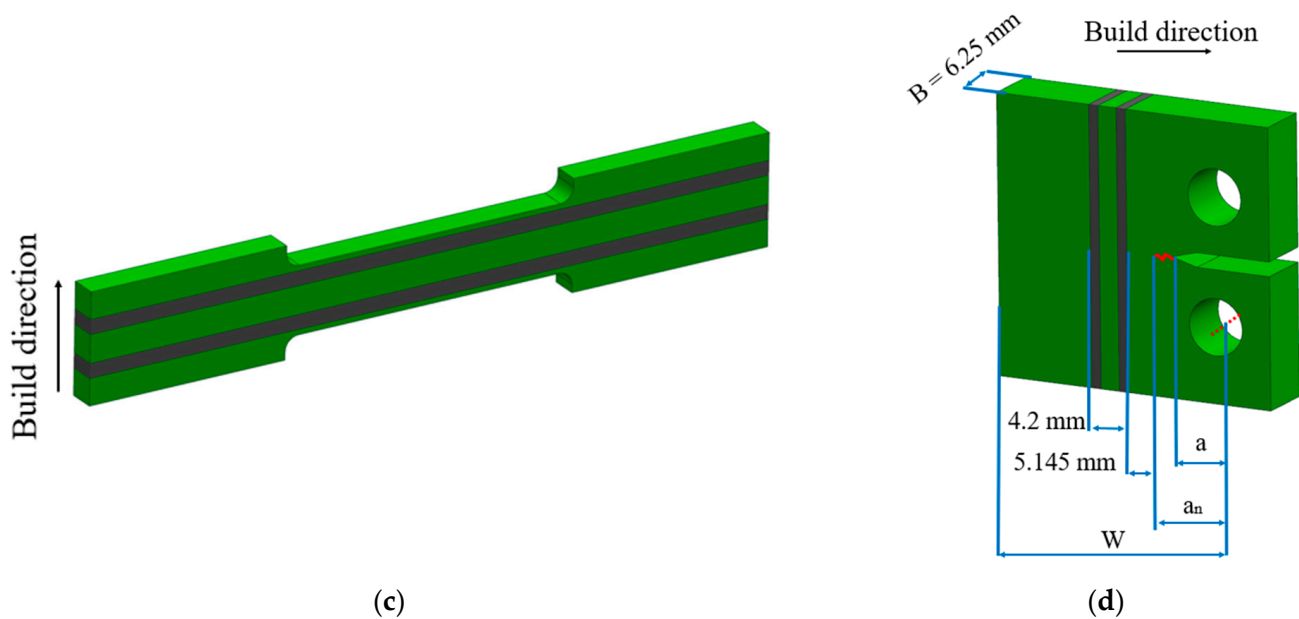


Figure 2. The multi-material Ti6Al4V/Cp-Ti samples for tensile tests and measurement of fatigue crack growth rate: (a) multi-material sample III (MMSIII) for tensile tests and (b) MMSIII for measurement of fatigue crack growth rate; (c) MMSII for tensile tests and (d) MMSII for measurement of fatigue crack growth rate.

Workpieces of the multi-materials after production with SLM are presented in Figure 3 (before mechanical and heat treatment).

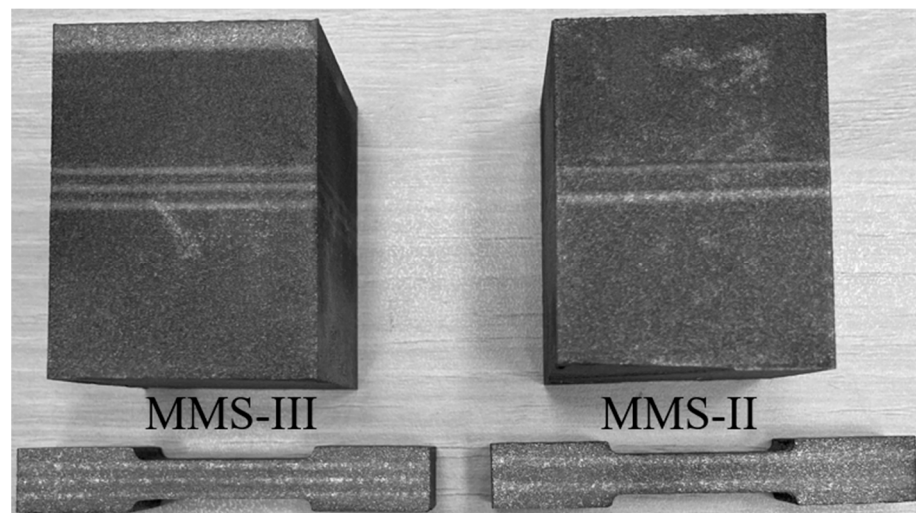


Figure 3. Workpieces of the multi-materials after production with SLM.

2.3. Post-Treatment and Characterization

Heat treatment was performed using a vacuum furnace (Carbolite Gero GmbH & Co. KG, Neuhausen, Germany). The treatment was conducted at a vacuum level of 10^{-3} to 10^{-4} mbar, following the given parameter set: heating at a rate of $10\text{ }^{\circ}\text{C}/\text{min}$, treatment temperature set to $1050\text{ }^{\circ}\text{C}$ and holding time for 2 h. The optical microscope Leica DMi8 M (Leica Microsystems, Wetzlar, Germany) was used to examine the microstructure. Etching of the materials was performed utilizing Kroll's reagent comprising 83% distilled water, 14% HNO_3 and 3% HF . The chemical composition was studied using the scanning electron microscope Mira 3 (TESCAN, Brno, Czech Republic), equipped with an energy-dispersive X-ray spectroscopy module. Microhardness was measured using the Vickers MicroMet

5101 microhardness tester (Buehler Ltd., Lake Bluff, IL, USA). To conduct mechanical tests, a Zwick/Roell universal uniaxial floor-type testing machine was used (Zwick Roell Group, Ulm, Germany). Tensile tests were performed on the Zwick/Roell—Z050 machine at a tensile speed of 0.3 mm/min. Fatigue crack growth rate measurements were made according to ASTM E647—15 using a servohydraulic fatigue testing system Instron 8801 (Illinois Tool Works Inc., Glenview, IL, USA). The measurements were conducted under a constant force of 2142 N.

3. Results and Discussion

3.1. Porosity and Microstructure of the Multi-Material Ti6Al4V/Cp-Ti Samples

The results of the porosity and microstructure study of MMS-III are presented in Figure 4. For the microstructure study, etching was carried out on the samples to distinguish between Ti6Al4V alloy and Cp-Ti. It can be observed from Figure 4a that the multi-material Ti6Al4V/Cp-Ti sample has a few small spherical pores. These pores are observed in both the Ti6Al4V alloy and Cp-Ti. Hot isostatic pressing may help reduce the number of such pores.

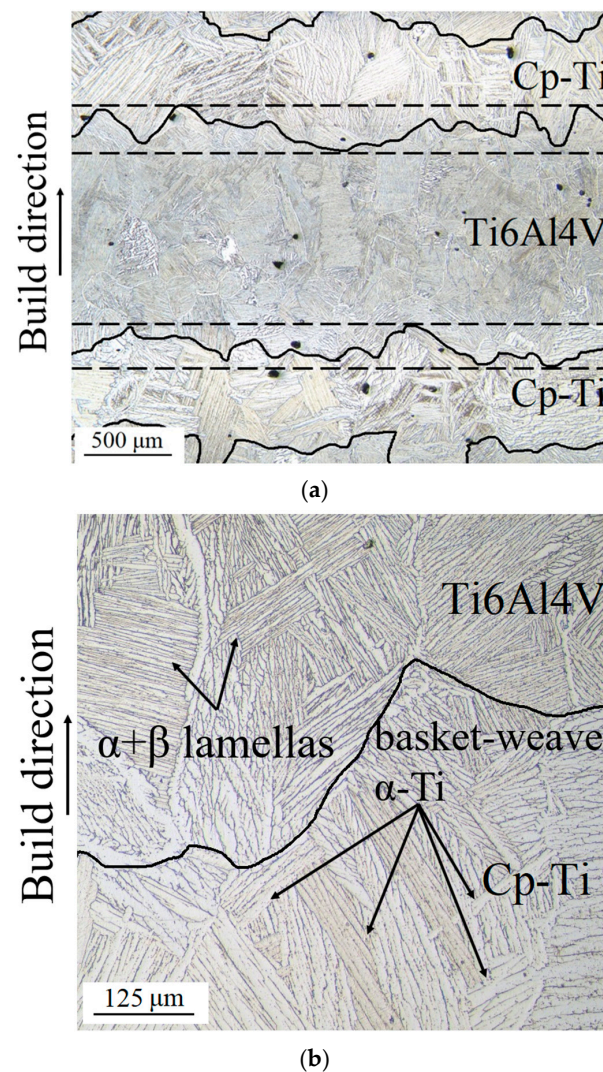


Figure 4. Microstructure of the multi-material Ti6Al4V/Cp-Ti sample: (a) general view of MMS-III microstructure, where solid lines are the geometry of the Cp-Ti layers, dashed lines are the borders of interfacial zones; (b) microstructure in the interfacial zone of MMS-III.

The curvilinear geometry of the Cp-Ti layers with varying widths is evident in Figure 4a (displayed as solid lines). The microstructure analysis shows that the layers have an average size of 500–700 μm . The curvilinear geometry of the Cp-Ti layers can be explained by the mixing of this metal and Ti6Al4V alloy during melting. Regions bounded by horizontal straight dashed lines can be identified in Figure 4a. These regions can be considered an interfacial zone since they contain both alloys. The interfacial zones had an average size of 250–300 μm .

The microstructure of MMS-III in the Ti6Al4V alloy region is characterized by $\alpha + \beta$ lamellae in a Widmanstätten form (Figure 4b). The thickness of the $\alpha + \beta$ lamellae differs depending on their orientation and the metallographic cross-section [27]. Heat treatment at 1050 °C promotes the formation of grains of different sizes due to incomplete recrystallization. The grains are round-shaped and consist of an initial β -phase grain that contains thickened α -phase plates [28]. In the Cp-Ti region, the microstructure comprises a Widmanstätten and basket-weave structure composed of α -phase. This structure is typical of cast titanium and can be explained by high-temperature heat treatment followed by slow cooling in the furnace [29]. It should be noted that there is diffusion of Al and V into Cp-Ti in the interfacial zone, which affects the resulting microstructure. This phenomenon may result in the creation of the β phase in the Cp-Ti region.

3.2. Chemical Composition and Hardness of the Multi-Material Ti6Al4V/Cp-Ti Samples

The alteration of MMS-III chemical composition is demonstrated in Figure 5a. There is a gradient change in Al and V while transitioning from the Ti6Al4V alloy to the Cp-Ti. Notably, the level of change in Al content exceeds that of V content. This can be attributed to the higher level of Al present in the Ti6Al4V alloy. Based on the alteration of Al content, it is possible to reassess the interfacial zone size, which is approximately 300 μm .

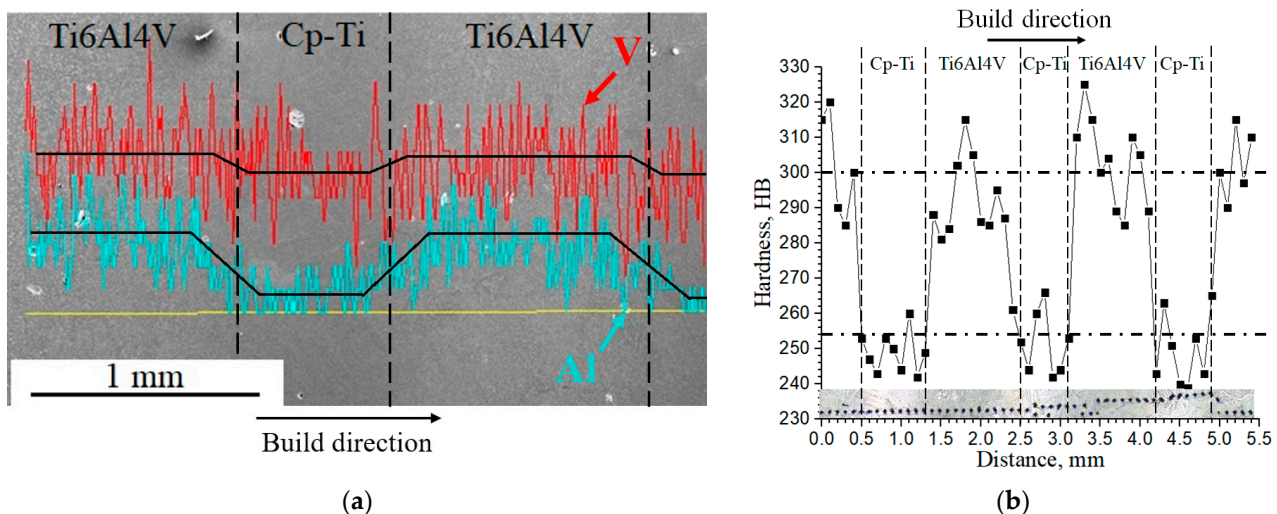


Figure 5. The alteration in the chemical composition and the hardness of the multi-material Ti6Al4V/Cp-Ti sample: (a) the alteration in chemical composition of MMS-III, where solid lines are the average value of element content, and dashed lines are the average location of interfacial zones; (b) the alteration in hardness of MMS-III, where dash-dotted lines are the average value of hardness, and dashed lines are the average location of interfacial zones.

The hardness variation in MMS-III is presented in Figure 5b. The Ti6Al4V alloy region exhibited an average Vickers micro-hardness of 300 HV, which decreased gradually to about 254 HV in the Cp-Ti regions. The application of heat treatment at 1050 °C led to a slight reduction in hardness for both the Ti6Al4V alloy and Cp-Ti [17].

3.3. Room-Temperature Tensile Properties and Fatigue Crack Growth Rates of the Multi-Material Ti6Al4V/Cp-Ti Samples

Table 1 presents the results of the tensile tests for MMS-III and MMS-II at room temperature along with the literature data for mechanical properties. MMS-III exhibited an ultimate tensile strength of 794 ± 12 MPa, and its elongation was $8.2 \pm 0.5\%$. MMS-II had an ultimate tensile strength of 816 ± 11 Mpa, and the elongation averaged $9.2 \pm 0.2\%$. The strength properties of both variants are similar, but MMS-II exhibits higher strength properties than MMS-III. The difference in the values of ultimate tensile strength varied by 3%, and elongation varied by 10%. It can be assumed that the slight decrease in the MMS-III properties is due to the larger length of the interfacial zones. The comparison of the results with the literature data, which is relative to pure Ti6Al4V alloy, reveals that there is a minor reduction in ultimate tensile strength (about 11% for MMS-III and 8% for MMS-II) and reduction in elongation (33% for MMS-III and 25% for MMS-II) [30–32]. Hot isostatic pressing may help improve the strength and ductility of the material by reducing its porosity [33].

Table 1. The results of the tensile tests for the multi-material Ti6Al4V/Cp-Ti samples at room temperature.

Types of the Multi-Material Ti6Al4V/Cp-Ti Samples	UTS, Mpa	Elongation, %
MMS-III	794 ± 12	8.2 ± 0.5
MMS-II	816 ± 11	9.2 ± 0.2
B. Vrancken et al. [30] for Ti6Al4V	840 ± 27	14.1 ± 2.5
S. Leuders et al. [31] for Ti6Al4V	945	11.6
D. Wang et al. [32] for Ti6Al4V	877 ± 16	11 ± 1
Everage for Ti6Al4V from references	887	12.2

The results of fatigue crack growth measurements for MMS-III and MMS-II are illustrated in Figure 6. The multi-material Ti6Al4V/Cp-Ti samples were examined by analyzing a 4.2 mm long section, where the alternation of the Ti6Al4V alloy and Cp-Ti layers was monitored for their impact on the fatigue crack growth rate. A fatigue crack growth kinetic diagram for pure Ti6Al4V alloy, MMS-III and MMS-II is demonstrated in Figure 6. Figure 6 indicates that in the analyzed area, the pure alloy curve conforms to Paris's law (straight dashed line). The curves of MMS-III and MMS-II deviate from the Paris's law curve (represented by lines with squares and circles in Figure 6). This line pattern of the curves confirms that the alternating layers of more and less ductile material impact the kinetics of fatigue crack growth. A detailed analysis of the MMS-III and MMS-II curves reveals an inertia in the reduction in the crack growth rate. Initially, the crack growth rate reduction is delayed as the crack propagates into the more ductile layers. Figure 6 illustrates that at the beginning of the analyzed section (10.3 mm), the crack growth rate in MMS-II should have decreased due to the presence of a more viscous layer. The decrease, however, began later (10.7 mm) and was completed after the ending of the viscous layer (11.4 mm). A comparable scenario can be noted for MMS-III, where the crack growth rate increases in the less viscous layer with lagging (11.3 mm). The presence of interfacial zones, where more ductile and less ductile materials coexist, could be the reason for this. As the crack propagates further, this pattern comes to a halt, and the material responds to the existence of ductile layers with increased sensitivity (11.35 mm, 12.1 mm, 12.7 mm, etc.). This, in turn, could be attributed to the overall decrease in the crack growth rate of MMS-III and MMS-II. Further, the graph provides evidence that, when fractures propagate in MMS-III and MMS-II, there is a smaller decrease in crack growth rates from layer to layer. An illustrative example is the 13.9 mm point, where the growth rate for MMS-III does not decrease and remains almost constant.

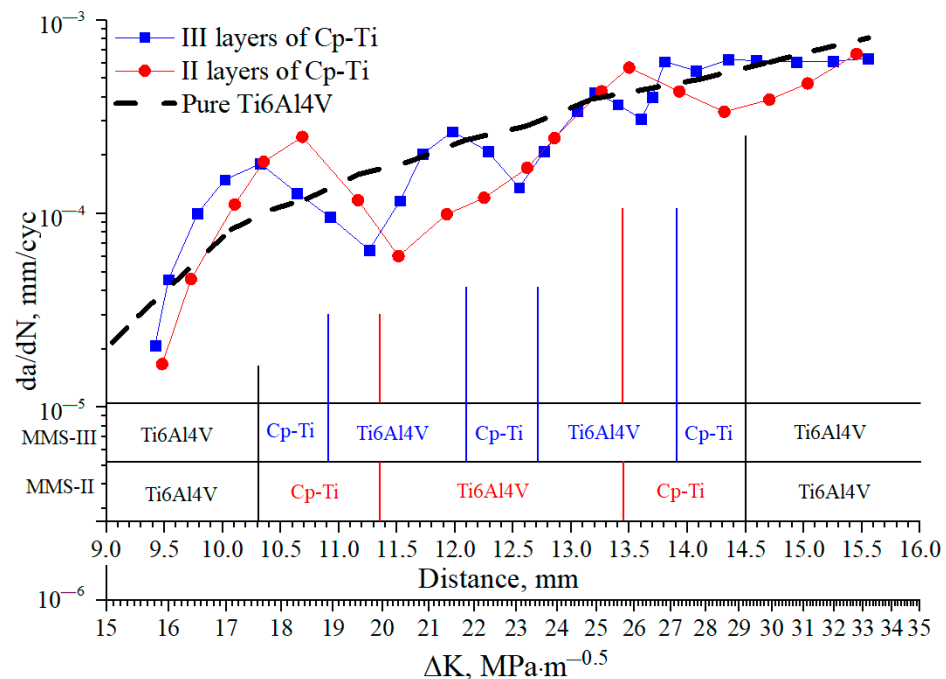
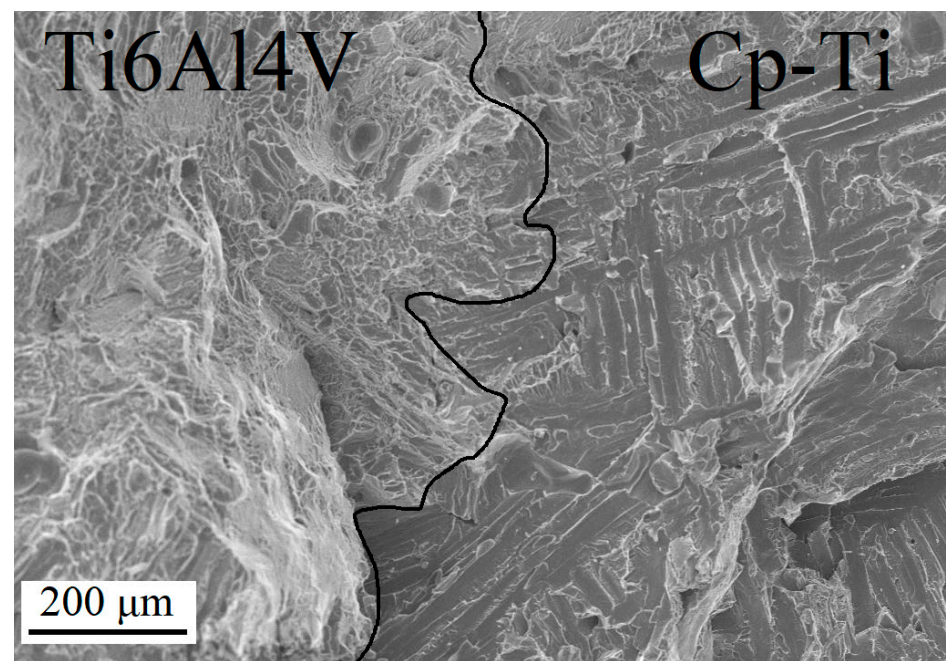


Figure 6. The results of fatigue crack growth rate measurements for the pure Ti6Al4V alloy and the multi-material Ti6Al4V/Cp-Ti samples—the fatigue crack growth kinetic diagram for pure Ti6Al4V alloy (straight dashed line), MMS-III (lines with squares) and MMS-II (lines with circles).

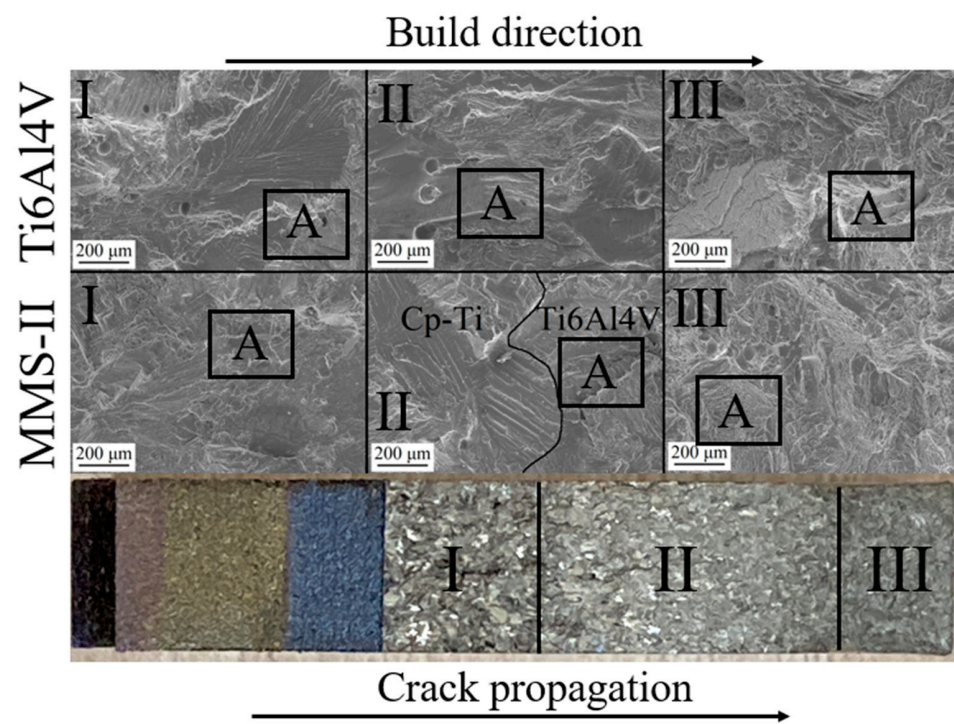
It is worth noting that, in this study, a variant in which more ductile layers were grown in a plane parallel to the plane of the main growth layers was investigated. As part of further research, it would be worthwhile to produce samples in which more ductile layers will be grown in a plane perpendicular to the plane of the main layers. Changing the plane in which the more ductile layers are grown could have an effect on the fracture toughness.

It can be noted that the base material being considered, Ti6Al4V alloy, has initially high fracture toughness values. In this regard, the difference in the local increase in properties may not be so clear. The obtained results confirm the principal possibility of a local increase in properties due to the creation of a multi-material structure in products obtained via L-PBF. This technological approach may be applicable to other titanium alloys (or to Ti6Al4V alloy after other heat treatments) and other metals. Therefore, further investigations are warranted to explore the local increase in fracture toughness through the creation of a multi-material structure in products obtained using L-PBF. Additional research is necessary to examine the enhancement in fracture toughness locally in multi-materials obtained via L-PBF. The objective of this research is to analyze the extent of the influence of this local enhancement in properties.

The results of fractographic studies after tensile and fatigue crack growth rate measurements are depicted in Figure 7. Figure 7a illustrates that after tensile tests, there is a minimal number of pores and microcracks in both the Ti6Al4V alloy zone and the Cp-Ti zone. In the Ti6Al4V alloy zone, there are dimples of varying sizes, consistent with the ductile fracture pattern of this alloy [34]. The Cp-Ti zone features grooves of almost equal size, which exhibit chaotic orientation, consistent with the Cp-Ti fracture pattern.



(a)



(b)

Figure 7. *Cont.*

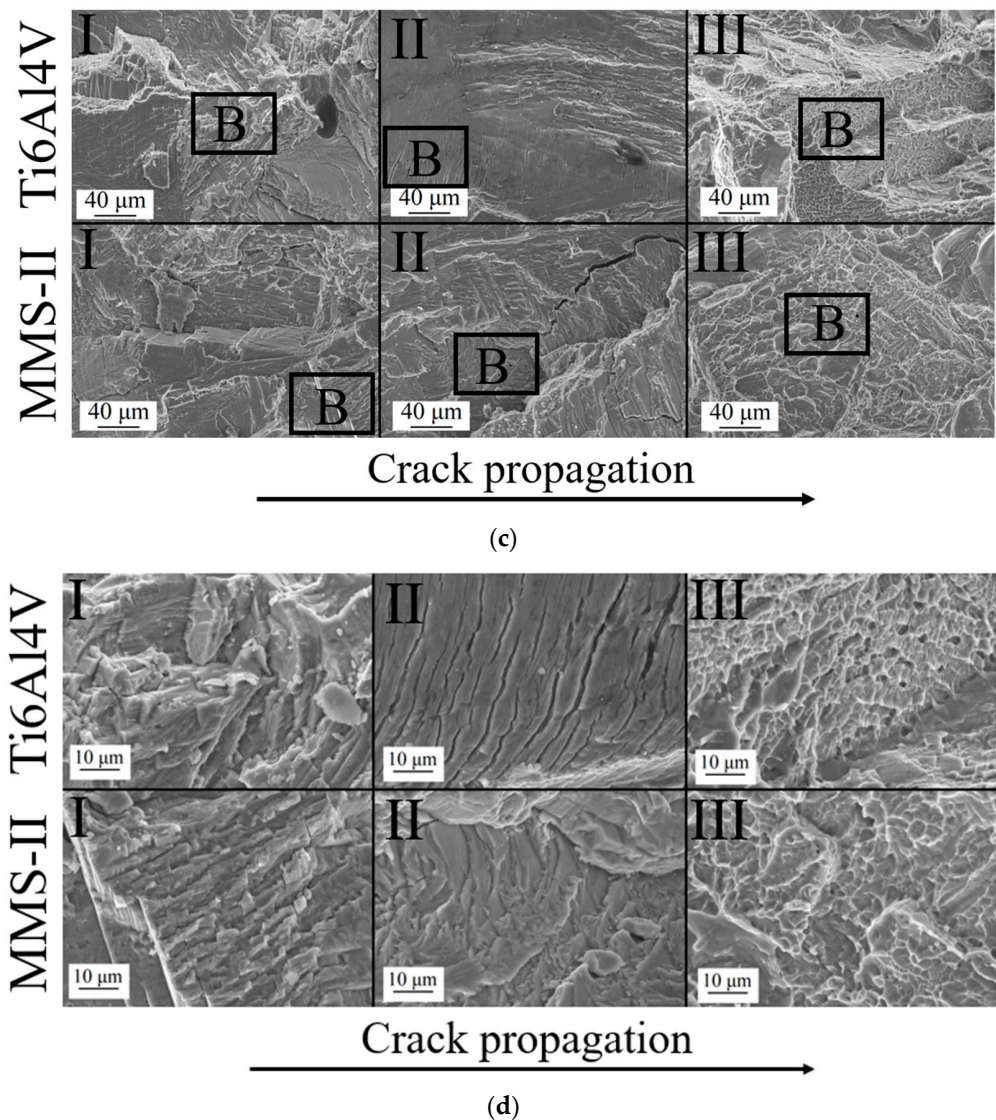


Figure 7. The results of fractographic studies after tensile test and fatigue crack growth rate measurement for the multi-material Ti6Al4V/Cp-Ti samples: (a) fracture surface after tensile testing; (b) fracture surface after fatigue crack growth rate measurement; (c) area A from at higher magnification; (d) area B at higher magnification. I–III—different sections of fatigue crack propagation.

Figure 7b–d display a comparison between two variants of fatigue crack propagation: a sample of pure Ti6Al4V alloy and MMS-II. Fatigue crack propagation features three different sections: a low crack growth rate section (section I depicted in Figure 7b), a section of constant crack growth rate (section II depicted in Figure 7b) and a section of high crack growth rate (section III depicted in Figure 7b). Regarding the considered variants (Ti6Al4V and MMS-II), a similar fracture pattern is observed. A flat fracture with micro-toothed ridges, parallel slip lines and fatigue strips characterizes sections I and II, as can be seen in Figure 7b–d. The presence of dimples of various sizes characterizes section III, which is like the fractographic pattern of the tensile specimen (see Figure 7a for Ti6Al4V alloy). After analyzing the effect of the more ductile layers of Cp-Ti on the nature of fatigue fractures, it is clear that the transition from the Ti6Al4V zone to the Cp-Ti zone does not result in delamination; the fracture surface is uniform. Both zones display a fatigue fracture with a complex, developed relief, characterized by the presence of mixed static and cyclic modes of loading. The fracture in the Cp-Ti zone (refer to Figure 7b for MMS-II, section II) is markedly distinct and like the tensile fracture (refer to Figure 7a for Cp-Ti).

4. Conclusions

The use of multi-materials allows for a localized improvement in the part properties and performance. It is worth noting that the fracture toughness in multi-material obtained via L-PBF has not been well explored. Thus, this study aimed to investigate the fracture toughness of multi-material Ti6Al4V/Cp-Ti samples, produced via L-PBF. Also, in this study, investigations were conducted into the microstructure, chemical composition, hardness and mechanical properties of the multi-material Ti6Al4V/Cp-Ti samples. The conducted research resulted in the following conclusions:

1. The size of the interfacial zone in the multi-material Ti6Al4V/Cp-Ti sample averaged between 250 and 300 μm . This was verified by examining the change in chemical composition (Al content) along the sample's cross-section.
2. The Ti6Al4V alloy zone had an average Vickers microhardness of about 300 HV, which decreased steadily to around 254 HV in the Cp-Ti zone. By comparing the results of the tensile tests with the literature data (of relatively pure Ti6Al4V alloy), it can be concluded that there is an insignificant decrease in tensile strength (by approximately 11% for MMS-III and by 8% for MMS-II) and a decrease in elongation (by 33% for MMS-III and by 25% for MMS-II).
3. The obtained results confirm the principal possibility of a local increase in the fracture toughness due to the creation of a multi-material structure in products obtained via L-PBF. Additional research is necessary to examine the enhancement in fracture toughness locally in multi-materials obtained using L-PBF. The objective of this research was to analyze the extent of the influence of this local enhancement in properties.

In this paper, Ti6Al4V/Cp-Ti multi-material samples, which are layered materials, were investigated. In these samples, the composition changed in parallel layers. In further works, we plan to produce and investigate samples in which the composition will change not only in one but also in other directions.

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Data Availability Statement: The main data are provided in the paper. Any other raw/processed data required to reproduce the findings of this study are available from the corresponding author upon request.

Conflicts of Interest: The authors declare no conflict of interest.

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