INVESTIGATIONS ON THE CONSOLIDATION OF TNM POWDER BY ADMIXING DIFFERENT ELEMENTAL POWDERS

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Abstract

In the conventional powder metallurgy (PM) process route, finished components are produced from metallic powder materials by pressing at room temperature followed by pressureless sintering in a furnace. This simple method for fast and cost-effective processing is not suitable for γ-based titanium aluminides. Due to their brittleness, these cannot be compacted in the conventional way. In order to qualify this group of alloys for the PM route, a possible solution is the addition of elemental titanium or aluminum powder. In this study, the basis is commercially available pre-alloyed TiAl44-4Nb-0.7Mo-0.1B (TNM) powder with high application potential for example in the aerospace industry. Investigations are carried out to determine the influence of different admixtures of elemental powders on the compaction result and the resulting mechanical properties. The TNM powder is mixed with pure titanium and aluminum powders and pressed to a compact using graphite as tool lubricant. The results show that the admixture of elemental powders enables the consolidation of TNM powder. However, depending on the load applied, a certain minimum proportion of the respective elemental powder is necessary to produce a compact. Furthermore, a significant influence on the relative density as well as the strength of the pressed product can be observed.

Keywords: Powder compacting, TiAl powder, powder mixture, mechanical properties

1. INTRODUCTION

Titanium aluminides, especially γ-based titanium aluminides (γ-TiAl), possess high stiffness, high specific strength, good corrosion resistance, high temperature resistance and a density of 3.9-4.2 g/cm³ [1]. These properties make them particularly interesting for the automotive and aerospace industries, e.g., as a substitute for titanium- or nickel-based alloys with the associated weight reduction.

They are however difficult to process due to their brittleness caused by the low number of sliding planes [2]. The processing of pre-alloyed TiAl powder within the conventional powder-metallurgical (PM) process route, consisting of die pressing with subsequent sintering, has not been possible so far [3]. With pre-alloyed powder, the alloy composition of the finished sintered material is already present in each powder particle, so that homogeneous properties are available without prior powder mixing [4]. Processing is currently carried out using the field-assisted sintering technique (FAST) or hot isostatic pressing (HIP) [5].

A potential solution to qualify the conventional PM route is to mix the brittle TiAl powder with ductile pure powder to enable consolidation by die pressing [6]. When producing a component from powder in the conventional PM route, the aim is to achieve a defined or the highest possible relative density after die pressing. Investigations showed that parameters such as material, particle shape and pressing load influence the resulting properties [7]. In 1967, Heckel [8] already reported an increase in relative density with increasing compaction load for iron, nickel, copper and tungsten powders. Machaka et al. [9] showed the influence of different particle geometries and the compaction load on the resulting relative density of titanium. Tiwari et al.

[10] mixed two different powders, elemental aluminum powder and elemental iron powder, and attained better compressibility by an increase in relative density with increasing pressure. Gethin et al. [11]reported, that the addition of ductile powder to brittle powder significantly improves compaction during die pressing. So far, the influence of admixing several different powders to a powder like TNM, which cannot be consolidated by simple die compaction, on the resulting properties of the compact has not been investigated. However, it can provide the basis for qualifying the conventional PM route for TNM.

In this study, the consolidation of commercial pre-alloyed TNM powder with the addition of elemental Ti and Al metal powders is investigated. The aim is to analyse the influence of different proportions of elemental powder additions on the consolidation of TNM powder. The results are evaluated based on the resulting relative density and tensile splitting strength [12].

2. MATERIALS AND METHODS

The basis of the study is the pre-alloyed γ-based TiAl44-4Nb-0.7Mo-0.1B (TNM) powder provided by the company GfE Gesellschaft für Elektrometallurgie mbH. The spherical particle size varies in the range of 45 to 150 μm. In order to be able to exclude an influence of the particle size and particle geometry[13], spherical elemental powders with a similar size (50 to 150 μm) were used. For this, Titanium Grade 2 of ECKART TLS GmbH and aluminum 99.5 of ECKA Granules Germany GmbH, hereinafter referred to as titanium and aluminum powders, were used. The elemental compositions according to the manufacturers are shown in **Table 1**. All powder percentages mentioned in the paper are presented in weight percent (wt%) unless stated otherwise.

Table 1 Chemical composition of TNM, Titanium Grade 2 and aluminum powder (wt%)

powder	Ti	Al	Nb	Mo	B	Fe	C	N	H	O
TNM	60.07	28.60	9.00	2.30	0.03					
Titanium Grade 2	≥ 99.3					≤ 0.30	≤ 0.08	≤ 0.05	< 0.01	≤ 0.25
Aluminum		99.5								

To produce the powder mixtures, the TNM powder was used as base material and mixed with different proportions of titanium or aluminum powder (**Table 2**, (1) and (2)). Additionally, titanium and aluminum powder were then added according to the titanium to aluminum ratio present in the TNM powder (**Table 2**, (3)). Furthermore, reference samples were prepared with 100% elemental powders. The minimum additions of the elemental powders to obtain a compact in one piece were determined in preliminary tests at increased loads. The powder mixtures described were pressed with 300 or 600 MPa in order to achieve a compact in one piece. To obtain a homogeneous mixture, the respective powder compositions were mixed for one hour in a 3D turbular shaker mixer of Willy A. Bachofen GmbH.

Table 2 Experimental design (wt%)

#	TNM	**50**	**40**	**30**	**20**	**0**
(1)	Titanium	-	-	70	80	100
(2)	Aluminum	50	60	70	80	100
(3)	Titanium/Aluminum	-	40.6 / 19.4	47.4 / 22.6	54.2 / 25.8	67.7 / 32.3

The subsequent processing of the powder took place in a conventional die compaction process. In order to achieve the most homogeneous density distribution possible, a floating die was used, which is mounted on springs to enable pressing on both sides when the pressing force is applied to one side to reduce the relative motion between die and powder. The experimental setup is shown in **Figure 1**. Before the start of each test, all contact points between tool and powder were coated with graphite spray to enable ejection after pressing [14]. To ensure best possible comparability, all samples produced should have the same dimensions, 20 mm in diameter and height at 100% compaction. The powder was compacted on a hydraulic hand press of MSE Teknoloji LTD with a pressure of 300 MPa and 600 MPa.

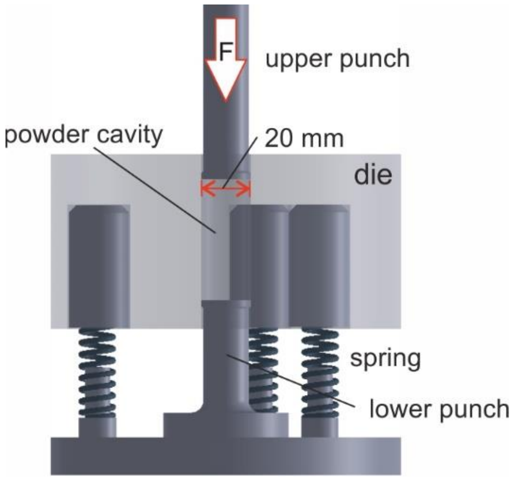

Figure 1 Experimental setup

The density of the compact was calculated by measuring weight as well as diameter and height. Then, the density was divided by the referential full density, which is 4.15 g/cm³ for TNM according to the manufacturer [15].In order, to characterise the overall bond quality between the powder particles, the tensile splitting strength was determined in accordance with DIN EN 12390-6:2010-09 [16]. The sample was placed on a flat metal plate and loaded radially with a test specimen in the form of a cylindrical pin until failure. Primarily, the required force was recorded by means of a load cell. According to the standard, the splitting tensile strength f_c is calculated using the following formula [16]:

$$f_{ct} = \frac{2 \times F}{\pi \times L \times d} \quad (1)$$

where:

f_{ct} - splitting tensile strength(MPa)
F - maximum load (N)
L - length of the contact line of the sample (mm)
d - specified cross-sectional dimension (mm)

3. RESULTS AND DISCUSSION

The relative densities of the pressed parts made of TNM powder after the addition of different proportions of elemental titanium or aluminum (left) and titanium and aluminum powder (right) at different pressing loads are shown in **Figure 2**. Comparatively high proportions of elemental powder, 50 or 60% aluminum and 70% titanium powder are necessary to produce a compact at all, because as obtained in the preliminary tests, TNM is not processable through die compaction, unlike the elemental powder. In this context, ductile material can be pressed better than brittle material [6]. In relation to the titanium powder, a lower proportion of aluminum is necessary in the TNM for the successful production of a compact. Also, the addition of aluminum powder leads to a higher relative density than the addition of titanium powder. The necessary proportion of aluminum for the production of a compact and to obtain the highest possible density depends strongly on the pressure used [7]. Thus, at a pressing load of 300 MPa, more aluminum is required to produce a compact than at 600 MPa

(**Figure 2** (left)). The relative density of the compacts increases with a higher proportion of aluminum powder, while at the same time the influence of the pressing load decreases. With 100% aluminum powder, an almost complete compaction is achieved with relative densities of approx. 98% at both applied loads [17]. With the addition of elemental titanium powder, it was not possible to produce an intact compact in one piece at 300 MPa pressing load, so a corresponding reference with 100% titanium powder was not used. In the experiments carried out at 600 MPa, a similar effect to the addition of aluminum powder was observed. With increasing titanium content, the relative density increases until it reaches about 86±5% at 100% titanium, which is consistent with the literature [9].

When titanium and aluminum powders are used according to the ratio present in the TNM powder, a minimum proportion of 60% in the TNM powder is required at 600 MPa pressing load, while 70% is required at half of that load to produce an intact compact (**Figure 2** (right)). When the elementary powder proportion is raised further, the relative density increases until it reaches 90±1% at 600 MPa pressing load and 79±1% at 300 MPa for 100% titanium and aluminum powder. Both values are below the relative densities that result from pressing exclusively aluminum powder.

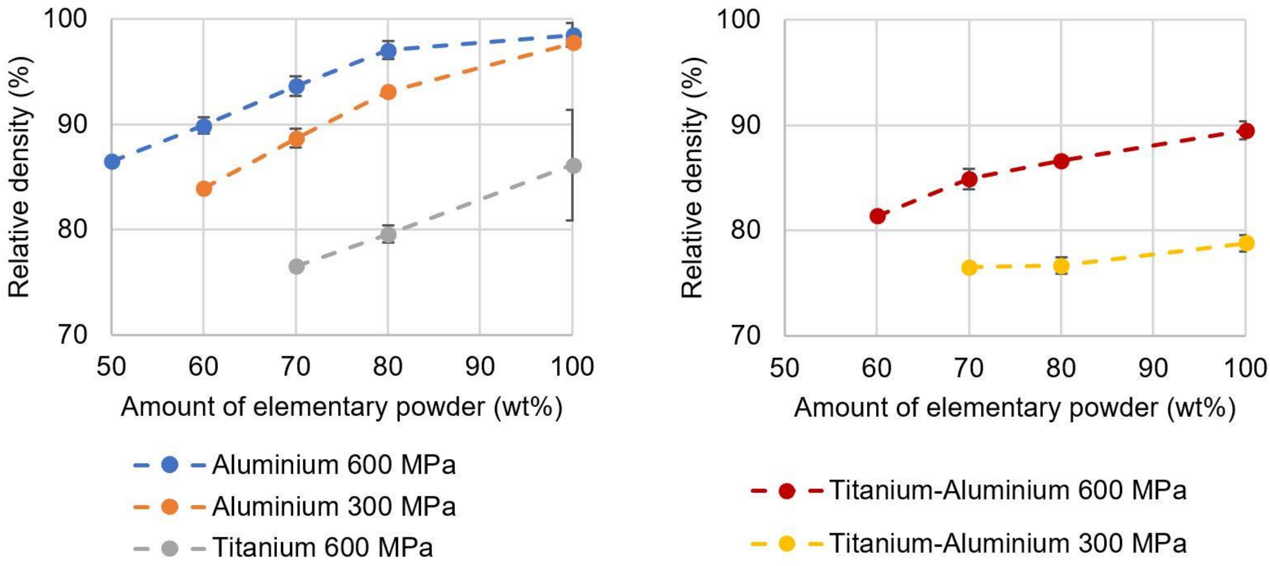

Figure 2 Relative density as a function of different proportions of elemental titanium or aluminum powder (left), titanium and aluminum powder (right)

Figure 3 shows the results of the tensile splitting tests of the samples compacted at a pressing load of 300 or 600 MPa with different admixtures of elemental aluminum or titanium (left) as well as aluminum and titanium powder (right). The trend observed in the relative densities (**Figure 2**) continues here. As the proportion of elemental powder increases, the tensile splitting strength tends to increase from 1.6±0.2 MPa (with 50% aluminum powder and 600 MPa load) to 5.4±1.1 MPa (100% aluminum powder, 600 MPa load). The tensile splitting strengths of samples produced at lower loads (300 MPa) follow a similar trend to the respective relative densities. Thus, when aluminum powder was added, no dependence of the strength on the pressure load can be observed. An exception is observed for the samples with 60% aluminum content. There, significant fluctuations in strength can be observed. A possible cause could be the uneven application of lubricant to the die. As a result, the friction on the die wall was higher during ejection, which resulted in a higher load, and most likely in non-visible pre-damaging of the compact. When titanium powder was added, the splitting tensile strength was below the values for aluminum powder addition, analogous to the corresponding relative densities. Consequently, the bond is better when using aluminum instead of titanium powder. Aluminum is much more ductile than titanium and has a lower yield strength, which is why it is easier to compress [18].

The admixture of titanium and aluminum powder also leads to an increase in tensile splitting strength as the proportion of TNM decreases. Its maximum value at 600 MPa pressing load is 5.7±0.9 MPa, which corresponds to the approx. value of the samples made of 100% aluminum powder. The addition of titanium should have reduced the resulting strength towards aluminum, analogous to the corresponding relative densities. However, it did not; the tensile splitting strength has further increased to a value similar to that of 100% aluminum. A possible cause could be the uneven application of lubricant. At lower pressing load, the tensile splitting strength is also significantly lower just like the corresponding relative density.

Although the tensile strength of the respective solid TNM material is significantly higher than that of titanium and aluminum, the tensile splitting strength of the powder compact increases progressively as the proportion of TNM decreases. However, the final mechanical properties are a result of subsequent heat treatment or the subsequent sintering process [7].

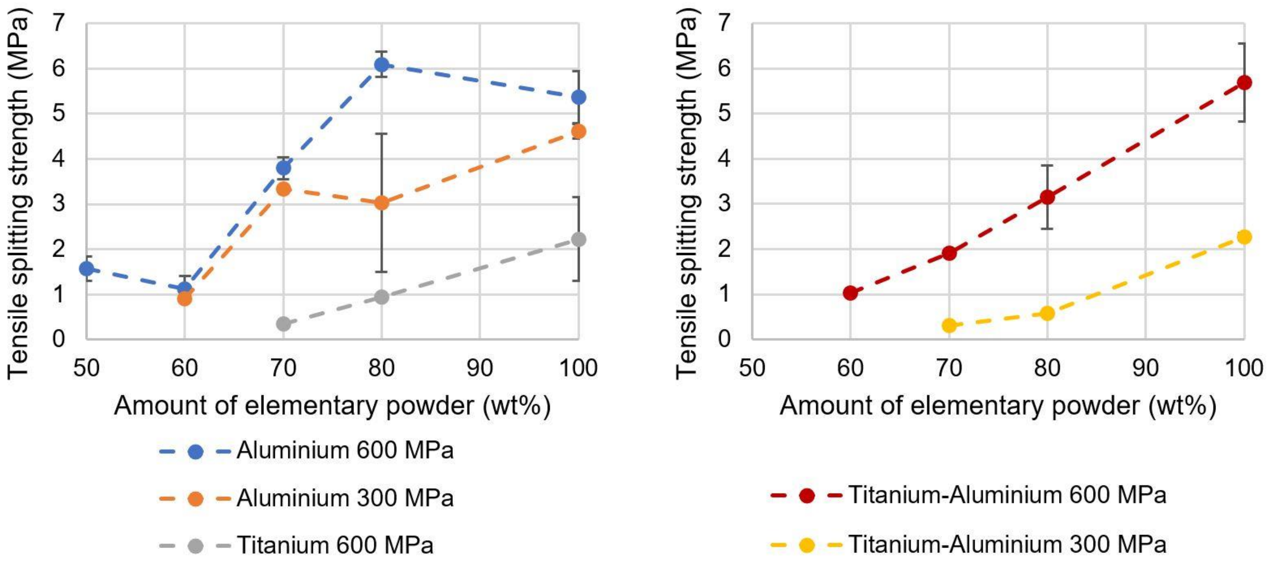

Figure 3 Tensile splitting strength as a function of different proportions of elemental titanium or aluminum powder (left), titanium and aluminum powder (right)

4. CONCLUSION AND OUTLOOK

Within the scope of the investigations, the influence of the admixture of different volume proportions of the main alloying elements of TNM, titanium and aluminum, in the form of elemental powders on the compaction of TNM powder during die pressing was examined. It was found that a reduction of the TNM powder proportion leads to increases in the relative density and tensile splitting strength. Consequently, as the proportion of elemental powders increases, the compressibility of the admixture increases as well. This can be attributed to the fact that the comparatively ductile powders aluminum and titanium are generally easier to press than the brittle TNM powder. Since aluminum is more ductile than titanium, the relative density and tensile splitting strength increase more rapidly with increasing proportions of aluminum powder than with increasing proportions of titanium powder. The admixture of both titanium and aluminum powders is less effective. In addition, the powder consolidation improves when the pressing load is increased. In order to obtain a higher density one possibility is to further increase the pressing load, change the particle size, to use a different particle geometry as well as a different lubricant. However, comparatively large proportions of elemental powder are necessary to produce a compact at all. At a pressing load of 300 MPa, no compact can be produced by adding only titanium powder, while 60% is required when aluminum powder was added. At a pressing load of 600 MPa, at least 70% titanium and 50% aluminum powder are required for successful part production. After obtaining a compact, the subsequent sintering process can take place. Usually, the final properties are adjusted there, which will be part of future investigations. The influence of the admixture of different proportions of the alloy powders on the microstructure and consequently the mechanical properties under different sintering parameters shall be characterized.

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