Investigating Optimum Parameters Required for Coiling GreenTitanium Strips

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Abstract. Titanium parts production using conventional processes is unarguably a costly process. Direct powder rolling process has shown its ability to produce titanium metal strips of various thicknesses and lengths. The present investigation aims to study the influence of process parameters such as roll gap, roll speed and roll set width and the green strip properties on the coil-ability of the strips. The study was conducted for roll gaps of 0.1 mm, 0.3 mm and 0.5 mm for varying roll speeds of 5 rpm, 10 rpm and 15 rpm. The roll set width was varied between 16 mm and 50 mm. Powders of Ti sponge 18 mesh (-1000 µm), TiHDH 100 mesh (-149 µm) and TiH2 CHI 100 mesh (-149µm) were roll compacted. Ti sponge green strips were coil-able after roll compaction at a roll gap of 0.3 mm, roll speed of 5 rpm and set widths of 16 mm and 50 mm. TiHDH green strips could not be coiled due to the brittle nature of the strips. TiH2 powder displayed poor rollability and could not be coiled. It was concluded that coil-ability is dependent on sufficient strength and ductility that the material has and strength and ductility depends on the rolling parameters used and the starting powder morphology and composition.

Keywords: Please list your keywords in this section.

1 Introduction

Titanium and its alloys have been used in the aerospace, defense, medical and other industries due to their excellent mechanical and chemical properties such as corrosion resistance in most corrosive environments, bio-compatibility and high-strength-to-weight ratio that is maintained at elevated temperatures [1], [2]. As a result, the demand for titanium parts is increasing. However, the high costs of the material and processing are a setback towards the widespread use of this fourth most abundant material on earth. Some of the reasons behind the high pricing of titanium lie in the high affinity of titanium to react with other small elements such as hydrogen, nitrogen and oxygen which make it difficult to process. This has led to the development of various titanium processing techniques to reduce the cost in the primary and secondary processing of titanium [1], [3].

When it comes to metal forming processes, powder metallurgy is regarded as one of the processes in which the benefit of reducing costs can be realized [4], [5]. Due to near net shape components produced, little material wastage is achieved in powder metallurgy as compared to conventional processes such as milling, grinding and turning [6]. The compaction and sintering of the samples give powder metallurgy an economic advantage, resulting in reduced material

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wastage as compared to wrought alloy processing while producing mechanical properties approaching those of wrought alloys. There are a number of powder metallurgy processes that have been widely used to reduce the costs associated with titanium processing. These include blended elemental approach, pre-alloying method, additive layer manufacturing, metal injection molding, spray deposition and direct powder rolling (DPR) [2]-[5].

Researchers all over the world have been striving to bring forward the solutions that enable the production of direct powder rolled products with good mechanical and physical properties while at the same time reducing processing costs. The DPR are used for the production of mill products, which may include plates, sheets, strips or foil [4], [5], [6], [7], [8]. Direct powder rolling (DPR) process is a multi-parametric process in which the control of each parameter is essential for the success of the process [9]-[15]. The DPR process consists of a number of stages: roll compaction of the strip, cold re-rolling of the green strip, multiple cold re-rolling of the strip and sintering [4], [5]. In an alternative DPR process, the Commonwealth Scientific and Industrial Research Organization (CSIRO) has developed a strip production process in which the green strip is produced by rolling powder through two opposite rotating rolls followed by hot rolling in a controlled atmosphere instead of sintering. The latter is regarded as a continuous process and aimed at reducing subsequent densification time in batch roll compaction and sintering processes [6], [7], [8].

The green strips produced through direct powder rolling may be long such that it's a challenge to store them and thermally process them particularly in the batch roll compact and sinter process. In order to address storage issues and facilitate thermal processing, it is suggested that coiling of the green strip may be a good practice.

Coiling may be described as a process of winding a length of strip metal into a joined sequence of rings.

In terms of research on the coil-ability of green metal strips, not much has been done. A literature search did not reveal detailed work on the rolling parameters and resulting properties required for the green strips to be coil-able. Li et al. [16], reported that roll compacted iron and silicon strips can be coiled using a 100mm diameter drum. The powder properties, rolling parameter and the resulting green strip properties are not mentioned for that alloy. On the other hand, Ro et al. [18], indicated that direct powder rolling of blended elemental titanium powders is a promising method to solve the many problems in DPR. They indicated that with the close control of rolling parameters such as roll speed, powder feed rate, roll diameter and roll separation, it is possible to achieve foils in the thickness range of 0.1-1.5% with densities in the range of 85-90%. For their blend, which contained 85 wt.% Ti-sponge fines, 80-90% density after roll compaction produced a coil-able foil. Hence, it is the aim of this study to investigate the rolling parameters and resulting green strip properties that will produce coil-able titanium green strips..

2 Experimental methods

2.1 Aim of experiments

The aim of this experimental procedure was to investigate the effect of roll compaction parameters such as roll speed, roll gap and roll width on the resulting properties of the green compacts that would produce green strips that are coil-able products. This work was based on the roll compaction of different titanium powders to determine the parameters for each titanium powder studied.

2.2 Description of materials

Ti sponge, Titanium Hydride Dehydride (TiHDH) and Titanium Hydride (TiH2) powders were roll compacted into strips of different lengths, widths and thicknesses. The powder particle size of 18 mesh (-1000 µm) for Ti sponge and 100 mesh (-149 µm) for TiHDH were used. The TiH2 powder was -149 µm (100 mesh). The sponge was supplied by AG materials and the TiHDH and TiH2 were supplied by Chengdu Huarui Industries (CHI) and the AG Materials. The chemical compositions of the three different powders used are presented in Table 1 and the particle sizes are given in Table 2.

Table 1. Chemical composition of Ti sponge 18 mesh, TiHDH CHI 100 mesh and TiH2 100 mesh powders in wt %.

	Ti	Cl	Fe	O	N	C	H	Ni	Si
Ti sponge	>99	0.04	0.11	0.10	-	0.005	0.015	0.019	0.02
TiHDH 100 mesh	>99	0.04	0.035	0.18	0.025	0.02	0.03	-	0.02
TiH_2 CHI 100 mesh	>99	0.035	0.03	0.15	0.03	0.02	3.8	-	0.01

Table 2. Particle size and shape for Ti sponge 18mesh, TiHDH 100mesh and TiH2 CHI 100mesh powders.

	Powder supplier		
	Ti sponge	TiHDH (100 mesh)	TiH_2 CHI (100 mesh)
Size distribution (µm)	-1000 µm	-150 µm	-150 µm
D_{10}	719	30.6	25.2
D_{50}	890	113	67.3
D_{90}	1114	179	131
Sphericity	0.75	0.83	0.89
Roundness	0.55	0.64	0.66

2.3 Description of equipment

Figure 1 shows the equipment used for the production of green strip samples using a roll compactor. It is a Schwabenthal T150 that has two opposite rotating rolls of diameter 170 mm and a roll face of 450 mm which was modified to roll metallic powders. The modification involved addition of a tungsten carbide sleeve with a roll face of 150 mm. The roll gap can be adjusted between 0.1 mm and 0.5 mm and the roll face between 0 to 150 mm using aluminum side plates mounted on the feed zone as in Fig. 1(b). The roll mill has a variable speed of 0-30 rpm. The rolls consolidate the metal powder into denser strips.

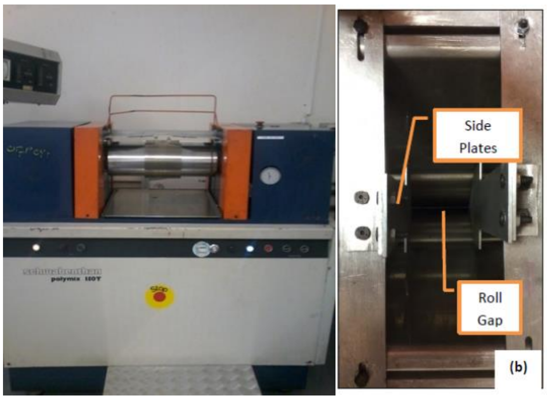

Fig. 1. Modified Schwabenthal T150 showing set rolling parameters.

2.4 Experimental procedure

The experiments were carried out on modified Schwabenthal T150 as shown in Fig. 1. The powder feed rate was controlled by pre-feeding the powder in the compaction area and during compaction, powder was manually fed constantly using a funnel to ensure that the powder remains at the same height during compaction.

Ti sponge, TiHDH and TiH2 powders were roll compacted into strips of different widths and thicknesses. The rolling parameters included rolling at different speeds, widths and roll gap. The three different powders were roll compacted at different rolling speeds of 5 rpm, 10 rpm and 15 rpm. The roll gap was set at 0.1 mm, 0.3 mm and 0.5 mm. The roll width was varied at 16 mm and 50 mm by adjusting the distance between the two side plates on the roll face. The green strip was coiled by manually bending it around a 50 and 100 mm diameter steel disks.

The powder used was weighed on an Ohaus Explorer balance. In order to achieve green strips of 200-400 mm length, a mass of 50 g for a 16 mm set width and 80-100 g for a 50 mm set width was used.

2.5 Specimen preparation

Density measurements involved the determination of the mass as well the volume of the strip. The masses of the green strips were measured using an Ohaus Explorer balance. The volume of the green strip was determined by measuring the dimensions of the strip such as the length, width and thickness using a Vernier Caliper and a micrometer screw gauge was used to compare or compliment the measured thickness of the strip. An average of 10 strip thickness values was measured. With regard to strip width, averages of 10 values of strip width were used. From the relationship of mass divided by volume (m/V), the density of the strips was determined and the percentage density with reference to the true density of commercially pure (CP) titanium (4.5 g/cm3) [10] was reported.

Specimens were ground and polished by the procedures and techniques for preparing titanium. The sample preparation was performed according to Struers guidelines and ASTM E3 on mechanical grinding and polishing.

On average 10 indentations were performed using a Vickers microhardness tester and average values were reported. In cases where samples did not have enough material, 7 indentations were performed. The Vickers microhardness tests were carried out in accordance with ASTM E384.

3 Results and discussion

Coiling has some advantages during sintering. Coiled green sheets can be batch sintered whereas uncoiled green sheets may only be sintered in a continuous fashion which would be challenging for titanium that requires an inert environment to minimize pick up of interstitial elements such as oxygen, hydrogen and carbon. Pick up of these interstitials can be detrimental to the mechanical properties.

3.1 Ti Sponge

Titanium sponge of (-1000 µm) size displayed good rollability. The density and Vickers microhardness (HV) test results are shown in Figure 2. Generally, highest densities were experienced at 0.1 mm roll gap, followed by 0.3 mm and 0.5 mm roll gap.

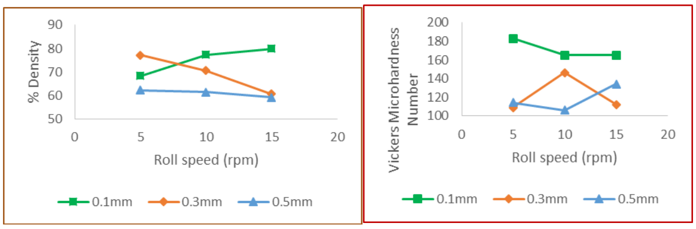

Fig. 2. Modified Schwabenthal T150 showing set rolling parameters.

From Figure 2, at 0.1 mm roll gap, the density increases from 68% at 5 rpm to 80% at 15 rpm. However, [11] has indicated that roll speed has no profound effect on the density of the strip. On the other hand, Bindumanavan [19] has indicated that increasing the roll speed decreases the density. But in the case of Ti sponge green strips at 0.1 mm roll gap, a trend was realized with the density increasing from 5 rpm roll speed to 15 rpm roll speed as opposed to what has been reported in [11] and [19]. At 0.3 mm roll gap, a decreasing trend was realized from roll speeds of 5rpm to 15 rpm. A decreasing trend was also realized at 0.5 mm roll gap. This suggests that there exists a transition in trends between 0.1 mm and 0.3 mm roll gaps, whereby an increasing trend at 0.1 mm roll gap changes into a decreasing trend at 0.3 mm and 0.5 mm roll gaps.

Highest HV values were generally discovered at 0.1 mm roll gap followed by 0.3 mm and 0.5 mm roll gaps, respectively. In terms of the HV values, a decreasing trend was realized at 0.1mm roll gap with increasing speed from 5 rpm to15 rpm. At 0.3 mm an increasing-decreasing trend was realized with a maximum HV value being observed at 10 rpm roll speed. In terms of the HV values at 0.5 mm roll gap, a minimum HV value was realized at 10 rpm roll speed.

Figure 3 shows coiled green strips of Ti sponge at 0.3 mm roll gap and 5 rpm roll speed for set widths of 16 mm and 50 mm. At these rolling conditions, the corresponding densities were high at around 80% and the hardness low at 105. High densities show the ability of the Ti sponge to interlock during roll compaction. This interlocking is expected due to spongy nature of the powders with low roundness as was measured at 0.55. The low hardness of the green strips shows that low work hardening could have occurred during roll compaction. This low hardening resulted in retention of some level of ductility of the Ti-sponge. Ti-sponge is expected to be ductile due to the low oxygen content which ultimately allows coil-ability of these strips.

Fig. 3. Coiled green strips of Ti sponge at 0.3 mm roll gap and 5 rpm roll speed for set widths of 16 mm and 50 mm.

3.2 TiHDH

This powder displayed good rollability. However, the trips were generally too brittle to be coiled. The densities and HV values of these strips are presented in Figure 4.

The density results revealed that at 0.1 mm roll gap, a minimum density of 70% was recorded at a roll speed of 10 rpm. At 0.3 mm roll gap, a maximum density was realized to be around 80%. The same can be said about densities at 0.5 mm roll gap, where a maximum density occurred at 10 rpm roll speed. Generally the densities obtained in TiHDH green strips were higher than those of Ti sponge with the highest densities been observed at 0.1 mm roll gap, followed by 0.3 mm and then 0.5 mm roll gap. The high densities show the ability of these powders to interlock and compact due to their low roundness which was measured at 0.64

A decreasing trend was observed for hardness at 0.1 mm roll gap from roll speeds of 5 rpm to 15 rpm. However at 0.3 mm roll gap, an increasing trend in the hardness was observed from 5 rpm roll speed to 15 rpm. At 0.5 mm roll gap, a decreasing trend in HV values was also observed. These high hardnesses show a much higher degree of work hardening of a powder that is expected to have a low starting ductility due to the higher oxygen content compared to Ti-sponge leaving little residual ductility to allow for coiling. In this case larger diameter disk might be needed to coil the strips as that will cause very minimal bending of the strip.

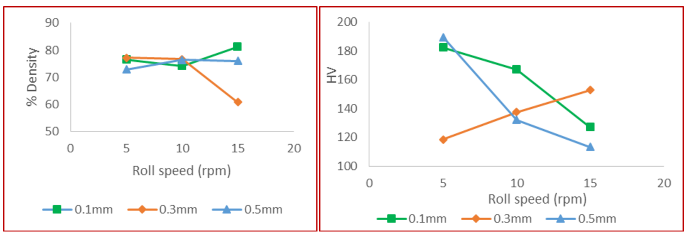

Fig. 4. Density and Vickers microhardness results of TiHDH for roll gaps of 0.1 mm, 0.3 mm and 0.5 mm for varying roll speeds of 5 rpm, 10 rpm and 15 rpm at a set width of 16 mm.

3.3 TiH_2 CHI 100 mesh

Roll compaction of TiH_2 CHI powder of 100 mesh size is a difficult process. The powder indicated poor rollability and therefore coiling green strips of this powder could not be achieved. The density and hardness results were obtained from the small pieces of the strip that held together post roll compaction. The densities achieved were very low in comparison to Ti–sponge and TiHDH powder. The strips were quite fragile and crumbled post roll compaction. The strips in other cases displayed the presence of cracks. This is supported by [10], who reported that titanium hydride is generally brittle and has relatively low strength. The brittle nature of the powder does support interlocking of particles to provide enough compact consolidation. The brittleness of TiH_2 is a result of the presence of high hydrogen content. Furthermore, cracking of the compacts reduces the chances of realizing coil-ability. Density and HV values recorded for TiH_2 CHI 100 mesh are presented in Figure 5.

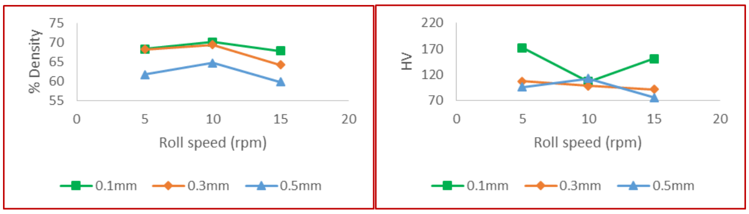

Fig. 5: Densities and HV values at 0.1 mm, 0.3 mm and 0.5 mm roll gaps for various roll speeds of 5 rpm, 10 rpm and 15 rpm at a set width of 16 mm.

4 Conclusions

Green strips of three different powders of titanium were produced by the roll compaction for varying rolling parameters. It was discovered that only green strips of Ti sponge could be coiled. The conditions for coiling these green strips were found to be optimum at 0.3 mm roll gap and 5 rpm roll speed for roll set widths of 16 mm and 50 mm. The density of the strip was 70% and its corresponding HV number was 165 for a 16 mm set width strip. For a strip at 50 mm set width, the coiling properties were density of 68% and HV value of 106. Other powders of TiHDH 100 mesh and TiH_2 CHI 100 mesh could not be coiled.

The roll gap was found to have a significant effect on the density and HV values. For all powders of Ti sponge, TiHDH, TiH_2 CHI 100 mesh, it was discovered that at smaller roll gaps of 0.1 mm, the densities and HV values were higher than those at roll gaps of 0.3 mm and 0.5 mm. Maximum and minimum densities and HV values were realized at 10 rpm roll speed. This indicates that optimum rolling parameters for titanium powders of Ti sponge, TiHDH, TiH_2 CHI 100 mesh and TiH_2 AG 100 mesh were at 10 rpm roll speed. Therefore, the roll speed has an effect on the density and HV values but depends on a particular powder being rolled.

Densities and HV values of green strips at 16mm set width were generally higher than those at 50 mm set width, with the exception being on TiH_2 AG 100 mesh at 50 mm set width which generally had higher density than those of TiHDH, Ti sponge and TiH_2 CHI 100 mesh under the same rolling conditions.

Coil-ability is dependent on sufficient strength and ductility that the material has and strength and ductility depends on the rolling parameters used and the starting powder morphology and composition.

Acknowledgements

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