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Effects of high power ultrasonic vibration on the cold compaction of titanium

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ABSTRACT

Titanium has widely been used in chemical and aerospace industries. In order to overcome the drawbacks of cold compaction of titanium, the process was assisted by an ultrasonic vibration system. For this purpose, a uniaxial ultrasonic assisted cold powder compaction system was designed and fabricated. The process variables were powder size, compaction pressure and initial powder compact thickness. Density, friction force, ejection force and spring back of the fabricated samples were measured and studied. The density was observed to improve under the action of ultrasonic vibration. Fine size powders showed better results of consolidation while using ultrasonic vibration. Under the ultrasonic action, it is thought that the friction forces between the die walls and the particles and those friction forces among the powder particles are reduced. Spring back and ejection force didn't considerably change when using ultrasonic vibration.

1. Introduction

Titanium and its alloys are widely used in the chemical, jewelry, aeronautical, aerospace and medical applications due to possessing a desirable combination of high chemical stability, high corrosion resistance, high specific strength and high biocompatibility [1]. Powder metallurgy is an extensively used manufacturing process for the near net shape fabrication of the titanium components since the material is relatively very expensive. Die pressing and sintering is the mostly used technology among all powder metallurgy processes [2,3]. Simplicity and low cost are the advantages of this process. However, fabricated samples suffer from low green density with poor mechanical properties and dimensional stabilities. Also, titanium has a poor compactibility [4]. However, the use of lubrication in the compaction of the titanium alloys has been avoided because of concerns about the introduction of impurities [5]. So, there is an interest in improving of low cost compaction of Commercially Pure (CP) titanium and titanium alloys [6].

Superimposing ultrasonic vibration on compaction process can be a solution to problems mentioned before. In previous studies, this technique has been used in manufacturing processes such as machining [7], grinding [8], metal forming [9], welding [10], impact treatment [11,12] and powder metallurgy. Various powders such as nickel, aluminum, tin [13], iron [14], copper [15], stainless steel [16], zirconium oxide [17] and nano-ceramics [15] have been cold compacted under the superimposed ultrasonic vibration. Results showed increased density, reduced compaction load and more uniform density of the compacted parts.

In order to overcome titanium cold compaction problems, the longitudinal high power ultrasonic vibration was used during the compaction. To date, no study about the influence of the high frequency vibration on the compaction behavior of titanium has been reported. In this study, ultrasonic vibration was superimposed on a uniaxial cold compaction process of titanium powders. The experiments were performed under three compaction pressures and different aspect ratios. In addition, the influence of powder size was also investigated.

2. Experimental procedure

Two commercially pure titanium powders with different particle sizes: (i) the purity of 99.9% with particle size <45 μm and (ii) the purity of 99.9% with particle size <150 μm were used in the experiments. Fig. 1 shows the morphology of the powders obtained from the scanning electron microscope (SEM) images. As seen, both powders are irregular shaped with an angular morphology.

Fig. 2 represents a schematic view of the designed ultrasonic assisted compaction system. It consists of three piezoelectric ultrasonic transducers, upper and lower punches, die, supporting fixture for holding the die during the compaction process and upper and lower load cells. This study investigates the effect of

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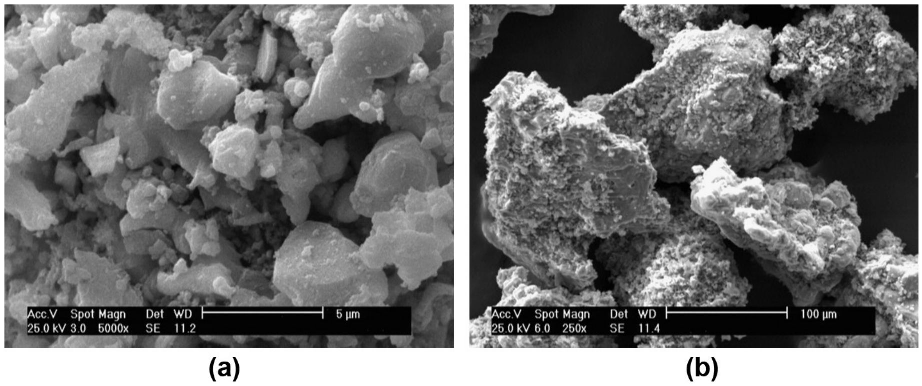

Fig. 1. SEM images of a) sub 45 µm and b) sub 150 µm commercially pure titanium powder particles.

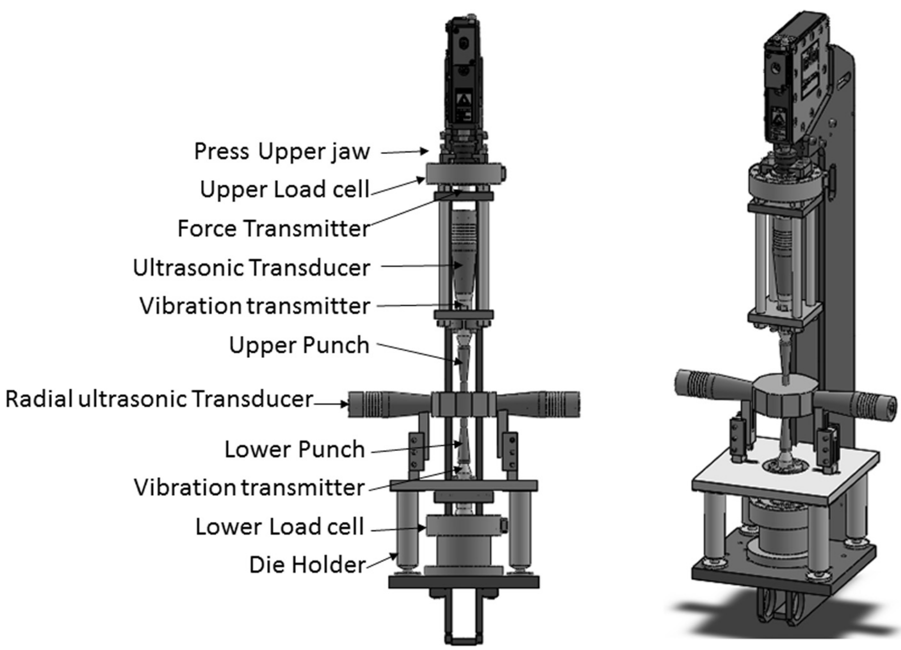

Fig. 2. Schematic of ultrasonic assisted powder compaction.

superimposed longitudinal ultrasonic vibration on the upper punch during the compaction. Ultrasonic transducers were designed and fabricated to be resonated at 25 kHz, so the punches and die were designed accordingly. ABAQUS finite element software version was employed for 2D and 3D modeling of transducers. Then, for evaluation of design by FEM method, transducers were fabricated and tested with network analyzer for finding of fundamental resonance frequency. There was good agreement between FEM and experimental results. Then, 3D finite element modelling was used to determine the longitudinal resonant frequency, location of nodal planes and mode shape of the punches, transmitters and die. A quadratic tetrahedral elements of type C3D10 were used in the modal analysis. So, dimensions of each part was determined by consideration of FEM results as well as von Mises failure criteria.

In this study, the effects of longitudinal vibration along the upper punch was investigated. First vibration is transmitted to the ultrasonic transmitter and then delivered to the powders through the upper punch. The two load cells were used to measure the pressure on upper and lower punches for determination of friction force on die. The two punches and the die were made of 58HRC tempered cold work steel 1.2379. Also, ultrasonic transmitters were fabricated from 1.6582 alloy steel. Compaction of cylindrical specimens with a diameter of 12.7 mm was conducted by a floating die system. Three aspect ratios of 0.5, 1 and 1.5 were considered. In order to obtain these aspect ratios, the amount of 2.5 g, 5 g and 10 g of powders were weighed and loaded into the die, respectively. Tests were performed at three pressure levels, i.e. 300 MPa, 400 MPa and 500 MPa. The variables are presented in Fig. 3. According to their adjustment condition, they are categorized in two groups: online parameters being controlled during the experiments and offline parameters being monitored after and before the compaction processes.

This system mounted on a universal compression testing machine (Fig. 4). Fixture was designed in order to support the die. First, a lower punch was inserted into the die hole and then a given amount of powder was poured into the die hole, and in the following the upper punch was moved down at a velocity of 1.5 mm/min and pressurized the powders. Ultrasonic vibration was applied on the upper punch as start to move. By densification of powders, the friction force between the particles and the die surface increases and causes the floating die to move down along with the punch movement. The compaction stops when the upper punch pressure reaches at the setting maximum pressure. In order