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Low frequency damping behavior associated with sintering process in Al powder compact

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Abstract: The internal friction behavior of Al green power compact duxing the sintering process was studied as a function of temperature. The internal friction measurements were performed from room temperature to 600 °C. Two typical internal friction peaks were detected corresponding to heating and cooling processes, respectively. The heating peak corresponds to a recrystallization process of deformed Al particles, which is influenced by many extrinsic parameters, such as measuring frequency, strain amplitude, heating rate, power particle size and compacting pressure. However, the intrinsic nature of the peak is originated from the micro-sliding of the weak-bonding interfaces between Al particles and increased dislocation density induced in compressing. The cooling peak with the activation energy of (1.64±0.06) eV is associated with the grain boundary relaxation, which can be interpreted as the viscous sliding of grain boundaries. The similar phenomena are also found in the Mg green powder compact.
Key words: Al powder compact; internal friction; sintering; grain boundary

1 Introduction

Sintering in powder metallurgy (PM) is generally defined as a process or phenomenon occurring with heating green powder compact under an appropriate temperature and atmosphere. The sintering plays a decisive role in the performance of the final products [1]. Therefore, to understand and describe the microstructure change of the green powder compact during the sintering process is of great importance. But the theoretical foundations for describing the sintering process in crystal metal powder compacts used in technical applications have up to now remained controversial [2]. During the sintering process of the metal powder compact, the powder contact boundary develops from poor mechanical bonding to strong metallurgical bonding. The driving force is generally considered as the reduction of free energy at the expense of minimizing the internal and external surfaces. However, the physical mechanisms on the driving force are still under discussion because of the complicated defect configurations induced in the metal powder compact [3,4].

Microstructure transition associated with the crystal defects evolution during the sintering process of the metal powder compacts has been widely detected by various techniques, such as position lifetime spectroscopy [1,5], transmission electron microscopy (TEM) direct observation [6], measuring shear viscosity or viscous Poisson's ratio [7]. In addition, the indirect measurements of electrical conductivity, thermal expansion, tensile strength, etc, are traditionally applied to understanding the sintering process [1]. However, the methods mentioned above are limited to a large extent due to the fact that the measurement of the samples in situ cannot be achieved. As a result, obtaining a dynamic changing rule of the microstructure during the sintering process is still a great challenge for metal powder compacts.

Internal friction (IF), Q^{-1}, is defined as energy dissipation from mechanical vibration energy irreversibly changing to thermal energy due to the intrinsic nature of materials, which is so sensitive to solid defects in materials that can offer detailed information even at atomic scale [8]. The Al particles during compressing are subjected to a severe deformation, as a result the powder compact is in a deformed state. Though the IF mechanical spectroscopy associated with the

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microstructure transition of the deformed metal materials has been widely investigated, such as Al−Mg alloys after cold-working with the deformation degree of 80% [9,10], pure Mg [11], Mg−Cu−Mn alloy [12] and ultra-fine-grained Cu [7,13,14] which were deformed through an equal channel angular pressing (ECAP); however, to detect and understand the sintering process of the green powder compacts using the measurement of IF has not been found as yet. In our previous study, an idea was proposed to understand the microstructure transition and crystal defects evolution of the green powder compact during the sintering process using the IF technique [15]. The results disclosed that the evolution law of grain boundary of the Al powder compact during the sintering process can be effectively detected according to the appearance of corresponding internal friction peaks. With the aim to obtain comprehensive and systematical information of the metal powder compact during the sintering process, the internal friction behavior of the Al powder compact was further deeply investigated. We are also expected that the results achieved are meaningful and helpful for better optimization of the sintering procedure.

2 Experimental

The elemental materials of Al and Mg powder with the purity of 99.99% were supplied by Sinopharm Chemical Reagent Co., Ltd., China. Different particle sizes with 70, 90, 130, 200 and 315 μm were achieved by a series of sieves. The green powder compacts of Al and Mg with the dimensions of 65 mm × 5 mm × 1.2 mm were prepared through an uniaxial compression under 400 MPa in a rectangular steel die for the measurement of IF. Any treatments for the metal powder compact were not carried out before IF measurement.

A multifunction internal friction apparatus (MFIFA), manufactured by Institute of Solid State Physics, Chinese Academy of Science, China, was used to measure IF. The MFIFA mainly consisted of an inverted torsion pendulum and an automatic computer controlled system. By setting different measuring parameters, the dependences of temperature, strain amplitude, frequency and time on IF can be correspondingly obtained. Reference [16] provides detailed information on the MFIFA. The measurement of IF was conducted under vacuum atmospheres of 1×10^{-3}−1×10^{-2} Pa. If there are no special instructions, the measuring frequency, strain amplitude and heating rate were set as 1.0 Hz, 10×10^{-6} and 2 °C/min, respectively. The characterization of microstructure of the green powder compact was performed using a Leica DMI−3000M optical microscope.

3 Results and discussion

Figure 1 shows the microstructure of Al green powder compact with a green density of approximate 0.80 ρ_0 relative to bulk Al where ρ_0 represents the density of bulk Al. The average particle size is about 70 μm. The grain particles have a lamellar morphology, which can easily cause an effective powder-particle size after compression. The size is slightly different from the particle size measured by screening analysis. This is because the Al particles were severely deformed during the compressing, leading to lots of very small Al particles and sometimes widening the area of Al compact.

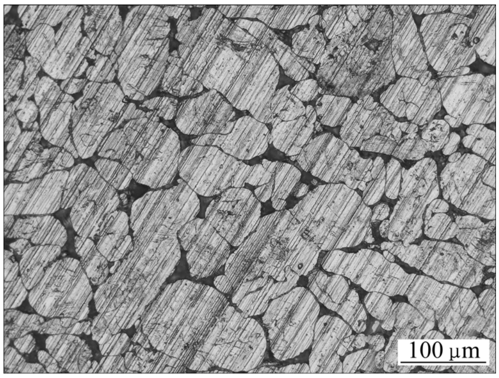

Fig. 1 Microstructure of Al green powder compact formed at 400 MPa

Figure 2 shows the typical IF and relative dynamic modulus (RDM) of the Al green powder compact during heating and cooling process from room temperature to 600 °C. The particle size of Al powder is 130 μm. It can be noted that the most outstanding feature is the appearance of two IF peaks corresponding to heating and cooling process, respectively. The positions of the peak temperature are separately at around 310 °C (named P_1) and 242 °C (named P_2) at the frequency of 1.0 Hz. The position of peak P_1 is independent on the measuring frequency. But the height of peak gradually decreases with increasing the measuring frequency. As a comparison, peak P_2 is dependent on measuring frequency which shifts towards higher temperature as the measuring frequency increases. In accordance with the appearance of the IF peaks, especially peak P_1, the RDM exhibits a much rapid drop. Peak P_1 is no longer observed during the cooling process and subsequent repeating heating process, which reflects a thermodynamically irreversible transition from green powder compact to a more equilibrium state. Peak P_2 is highly stable which always exists during cooling and repeated heating process after the first heating process. In other words, the appearance of peak P_2 should be related