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Short communication

# Strengthening and elongation mechanism of Lanthanum-doped Titanium-Zirconium-Molybdenum alloy

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ABSTRACT

The microstructural contributes to understand the strengthening and elongation mechanism in Lanthanum-doped Titanium-Zirconium-Molybdenum alloy. Lanthanum oxide particles not only act as heterogeneous nucleation core, but also act as the second phase to hinder the grain growth during sintering crystallization. The molybdenum substrate formed sub-grain under the effect of second phase when the alloy rolled to plate.

## 1. Introduction

Molybdenum has been widely used in the form of Titanium-Zirconium-Molybdenum (TZM) alloy [1]. The recrystallization temperature of the TZM alloy is also higher than that of pure Mo. ODS Mo (or Mo–La) consists of fine-grained molybdenum doped with lanthanum oxide particles. This material has extraordinary resistance to recrystallization and high-temperature deformation, and therefore, is suitable for applications requiring high strength at high temperatures. Oxide dispersion-strengthened (ODS) Mo alloy have been developed for nuclear applications [2].

To take advantage of these desirable properties, we designed a new type of Lanthanum-doped TZM (La-TZM) alloy in the form of a sheet by powder metallurgy and rolling which has good mechanical properties [3–7]. The effects of La element doping on TZM alloy plate after annealing and the doping method was analysed [4–6,9]. However, for the La-TZM alloy, the strengthening and elongation mechanism of La element in micro and nano-sized remind unclear. The microstructural influence on the tensile strength and elongation are still largely unknown. In this paper, we focuses on the sintered compact and plate microstructural influence on strengthen and elongation of La-TZM alloy which prepared by the method of solid-liquid doped La $(NO_3)_3$.

## 2. Materials and experimental

The chemical compositions of the TZM alloy and the La-TZM alloy are listed in Table 1. The La-TZM alloy specimens were prepared from the following main raw materials: pure Mo powder, $TiH_2$ powder, $ZrH_2$ powder, $La(NO_3)_3$, and graphite. The lanthanum doping was introduced in the alloy power by the solid-liquid doping method. The preparation process included mixing the powder, ball milling, compacting and sintering, followed by rolling into a 0.6 mm thick plate (90% deformation). The sheet was used for the follow-up performance testing and observation.

## 3. Discussion on the microstructure and mechanical properties

### 3.1. Mechanical properties of La- TZM and TZM alloy

Table 2 lists the tensile strengths and elongations of TZM and La-TZM sintering blank and plate. The sample dimensions shows in Fig. 1. Electronic universal tensile machine (WDW300, China) was used for the tensile strength and elongation and three repetitions were performed..

The tensile strength and elongation of the La-TZM sintering blank were measured to be 14.1% and 20.5% higher than the TZM sintering blank. Similarly, these properties of the La-TZM plate were increased by 40% and 26% respectively, compared to the TZM plate [5]. The stress-strain curves of TZM and La-TZM sheet shows in Fig. 1.

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**Table 1**
Design composition of TZM and La-TZM alloy (wt%).

| Sample | Ti | Zr | C | La | Mo |
|---|---|---|---|---|---|
| TZM | 0.50 | 0.10 | 0.02 | 0.00 | Balance |
| La-TZM | 0.50 | 0.10 | 0.02 | 1.00 | Balance |

**Table 2**
The mechanical properties of La-TZM and TZM.

| Material | Sintered blank | | Plate | |
|---|---|---|---|---|
| | Strength (MPa) | Elongation (%) | Strength (MPa) | Elongation (%) |
| TZM | 293.2 | 1.19 | 925 | 6.4 |
| La-TZM | 338.3 | 1.47 | 1295 | 8.09 |

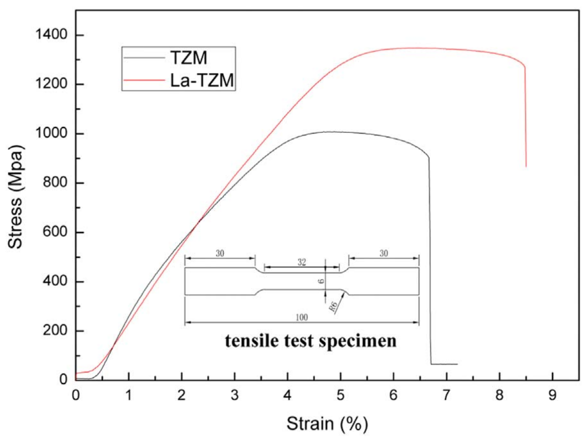


**Fig. 1.** The stress-strain curves and of TZM and La-TZM sheet.

### 3.2. *Strengthening effect of rare earth lanthanum on TZM alloy*

#### 3.2.1. *Refine crystal reinforcing*

The powder TZM alloy undergoes a series of physical and chemical changes during the sintering process: evaporation of water, removal of adsorbed gas, stress relieving, reduction in oxide powder particles surface, inter-particle mass transfer, recrystallization, and grain growth. The overall effect is to increase the contact surface between the crystal particles, causing the pores to shrink or disappear. The microstructure matrix of the TZM alloy exhibits recovery, recrystallization and grain growth in the sintering process [8].

Fig. 2 shows schematically the recovery- recrystallization- grain growth- crystalline phase process of the TZM alloy and the La-TZM alloy. Fig. 2(a) and (a') show the recovery; 2(b) and 2(b') the recrystallization; 2(c) and 2(c') the grain growth, and 2(d) and 2(d') the crystal phase. Fig. 2(a) and (a') show no change in the microstructure of La-TZM and TZM after recovery, but there is some second phase in the La-TZM matrix. Its microstructure, shown in the transmission electron microscopy (TEM) micrograph in Fig. 4(a) and in the schematic in Fig. 2(a'). Fig. 2(b') shows that the $La_2O_3$ in the La-TZM alloy acts as heterogeneous nucleation particles in the process of recrystallization, forming the second phase in the sintering process. This increases the recrystallization nucleation rate and promotes reduction in grain size after recrystallization. However, Fig. 2(b) shows that the grain size of the TZM alloy is obviously larger than that of the La-TZM alloy. As shown in Fig. 2(c) and (c'), the second phase particles $La_2O_3$ of La-TZM alloy also can pin on the grain boundary to hinder the movement of grain boundary in the grain growth process, so they can make the grain small by promoting grain nucleation and hindering grain growth. In contrast, the TZM alloy does not have the $La_2O_3$ second phase which could hinder the movement of the grain boundary, causing the grains to grow in size [9]. Part of the grain boundary migration will pass the second phase particle, so the $La_2O_3$ particles exist both inside the grain and at the grain boundary. Its microstructure, shown in the transmission electron microscopy(TEM) micrograph in Fig. 5(g) and in the schematic in Fig. 2(c'). Fig. 2(d) and (d') show the metallographic structures of the TZM and La-TZM alloy sintered billets. The grain size of the La-TZM alloy is seen to be much smaller than that of the TZM alloy, and is uniform..

Table 2 shows the mechanical properties of the La-TZM and TZM alloys. The average grain sizes of the samples are measured by the quantitative metallography method. As shown in Fig. 2(d) and (d'), The average grain size of TZM alloy sintered billet is 25.64 μm ± 8 nm, and that of the La-TZM alloy sintered billet is 14.26 μm ± 8 nm by measuring 30 grains. The difference in grain size is compatible with the recovery-recrystallization-grain growth mechanism of the alloys.

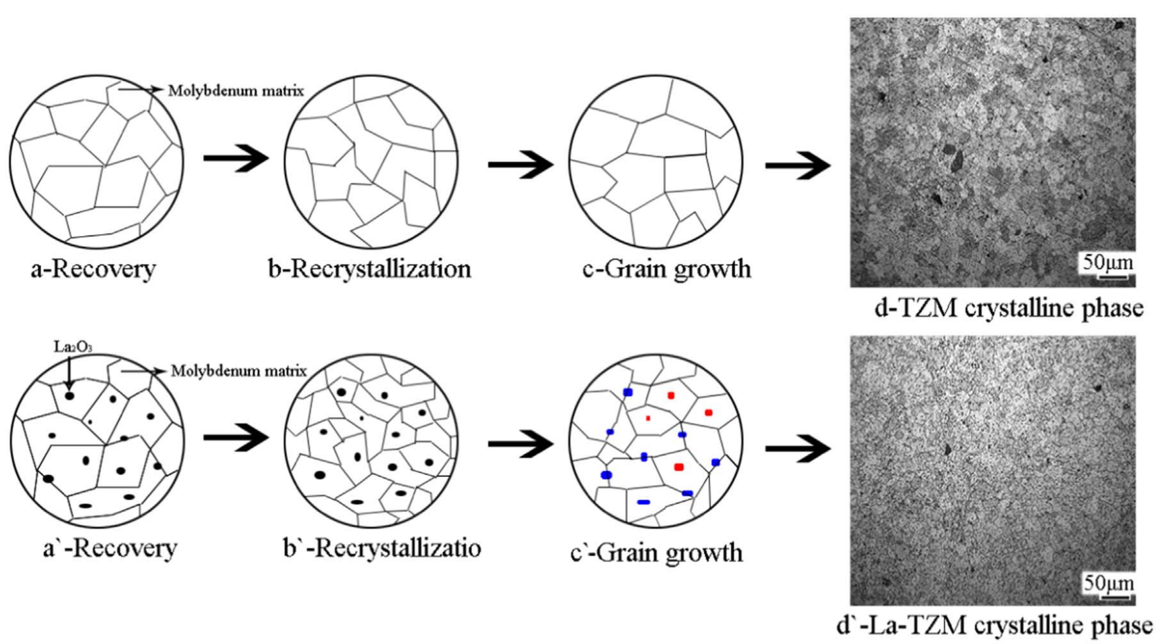


**Fig. 2.** Schematic diagram of recrystallization and grain growth TZM alloy (top row) and La-TZM alloy (bottom row).