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Densification Behavior of Rhenium Alloy for Non-Eroding Rocket Nozzle

Abstract

Rocket nozzle has been widely used to gain momentum in various application fields such as aerospace and defense industries. Since a performance of propulsion depends on a nozzle throat-area, the superior mechanical properties to reduce the erosion rate at the high pressure and temperature of more than 2200 °C are required. In order to satisfy such requirements, refractory metals or carbon – carbon composites have been widely used. Among them, rhenium alloy is one of the great candidates for rocket nozzle due to its unique mechanical properties such as a high melting point and strength. However, poor machinability restricts its use for large structural components, as single point machining is impossible. Considering its restriction on machinability, powder metallurgy (P/M) or powder injection molding (PIM) known as near-net-shaping method is a promissing process to produce rhenium alloy element. As the mechanical property is highly related to density, understanding the densification behaviors of rhenium alloy powders is of great importance and interest to successful sintering processes. Therefore, this study investigates the densification behavior using master sintering curve (MSC) with a minimal set of preliminary experiments.

1. Introduction

Rocket nozzle is widely used for a mechanical part such as a tactical missile, weather and surveillance satellite. Such a rocket nozzle works in the high temprature and pressure, because the enormous amounts of exhaust gas including a high temperature produced by combustion pass through throat-area which is the smallest cross-section area. Therefore, the material for rocket nozzle must have good mechanical properties such as a high melting point, a good thermal shock properties, and a low coefficient of thermal expansion to keep the performance of propulsion. In general, graphite and carbon-carbon composites have been widely used as nozzle materials to reduce the erosion rate of throat-area. However, the erosion rate of those materials is not enough to maintain propulsion. In this regard, there have tried to employ different types of materials to reduce increase of throat-area by erosion. The refractory metal is a representative material. As considering the thermal properties like a melting temperature, refractory metals are possible candidates for a noneroding rocket nozzle in the ultra high temerature and pressure [1].

This study investigates the densification behavior of W-25wt%Re and pure Re during sintering. Section 2 presents the preliminary backgrounds in MSC and ints sigmoid function representation. In Section 3, the experimental procedures including characteristics of W-25wt%Re and pure Re, experimental conditions and setups are briefly mentioned to produce the specimens. Section 4 presents the results of experiments and analysis of MSC. Finally, conclusions and contributions of this study are presented in Section 5.

2. Theory of MSC

The MSC model is described by a sigmoid function as follows;

$$\rho = \rho_0 + \frac{1-\rho_0}{1+\exp\left[-\dfrac{\ln\Theta - a}{b}\right]}. \tag{4}$$

The shape of sigmoid function representing the densification behavior is determined by constant parameters, *a* and *b*, which can be obtained by linearized form of MSC suggested by *Blaine et al.* [2].

3. Experimental Procedures

Dilatometry experiments (Dilatometer, DIL 402C) were carried out for investigating densification behavior during sintering. The samples were prepared by die pressing (DP) with all cylindrical shapes with a height of 15 mm and a diameter of 7 mm. The initial relative densities of W-25wt%Re and pure Re were approximately 0.44 and 0.42, respectively. These experiments were undergone in a H_2 atmosphere to keep Re from oxidizing on the surface as shown in Fig. 1.

4. Results and Discussions

The slope of curve and the value of *a* were calculated from curve fitting based on the linearized model. These values were used to define the MSC as shown in its sigmoid function form in Figs. 2 (b) and (d). Considering the correlation coefficient (R^2) of 0.996, the linearized curve with experimental data was well fitted. From the result of *n*, it is confirmed that the densification of pure Re is faster than W-25wt%Re. However, the halfway of densification for W-25wt%Re is lower than pure Re. It means that the densfication of W-25wt%Re is more activated than pure Re at the same temperature.

MSC was built by Ψ instead of ρ. By using Ψ, the densification behavior can be analyzed regardless of their different values of initial relative densities. Fig. 2 (b) and (d) show the MSC. The sigmoid function was well fitted with experimental data. The densification behavior was estimated up to the full density. Therefore, the entire range of densification behavior can be predicted. Considering MSC as shown in Fig. 2 (b) and (d), the sigmoid function of W-25wtRe is leftside than pure Re. This results of MSC are in agreement with the eariler result of the halfway of densification ($\Theta_{ref)}$)in linearized form.

5. Conclusions

Advanced high temperature materials are critical to enhance the performance of nozzle for rocket and hypersonic spacecrafts. In this regard, Re alloy is one of the most promising materials for high temperature material.

The densification behavior of the W-25wt%Re and pure Re was characterized using the dilatometry tests and MSC approach which can make densification behavior to be predicted as well as provides guideline to analyze sinter cycle design. As compared with pure Re and W-25wt%Re, the densification of pure Re is faster than W-25wt%Re. However, the W-25wt%Re is more easily densified at the relatively lower temperature. It indicates that W-25wt%Re can be more easily produced.

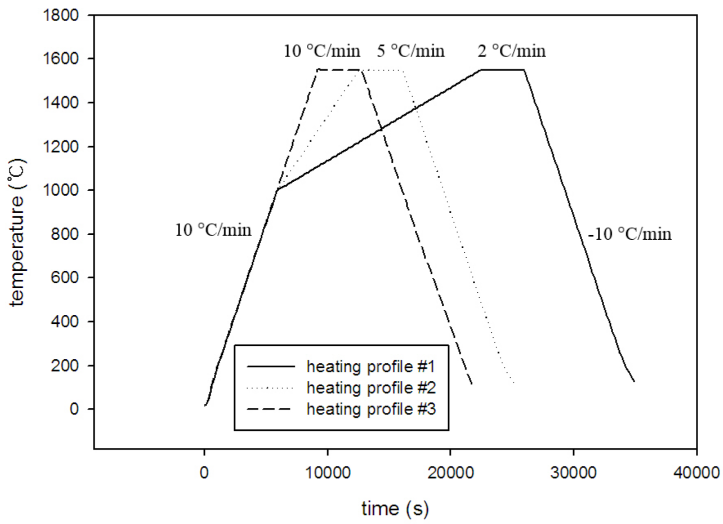

Fig. 1. Sinter cycle for dilatometry experiments.

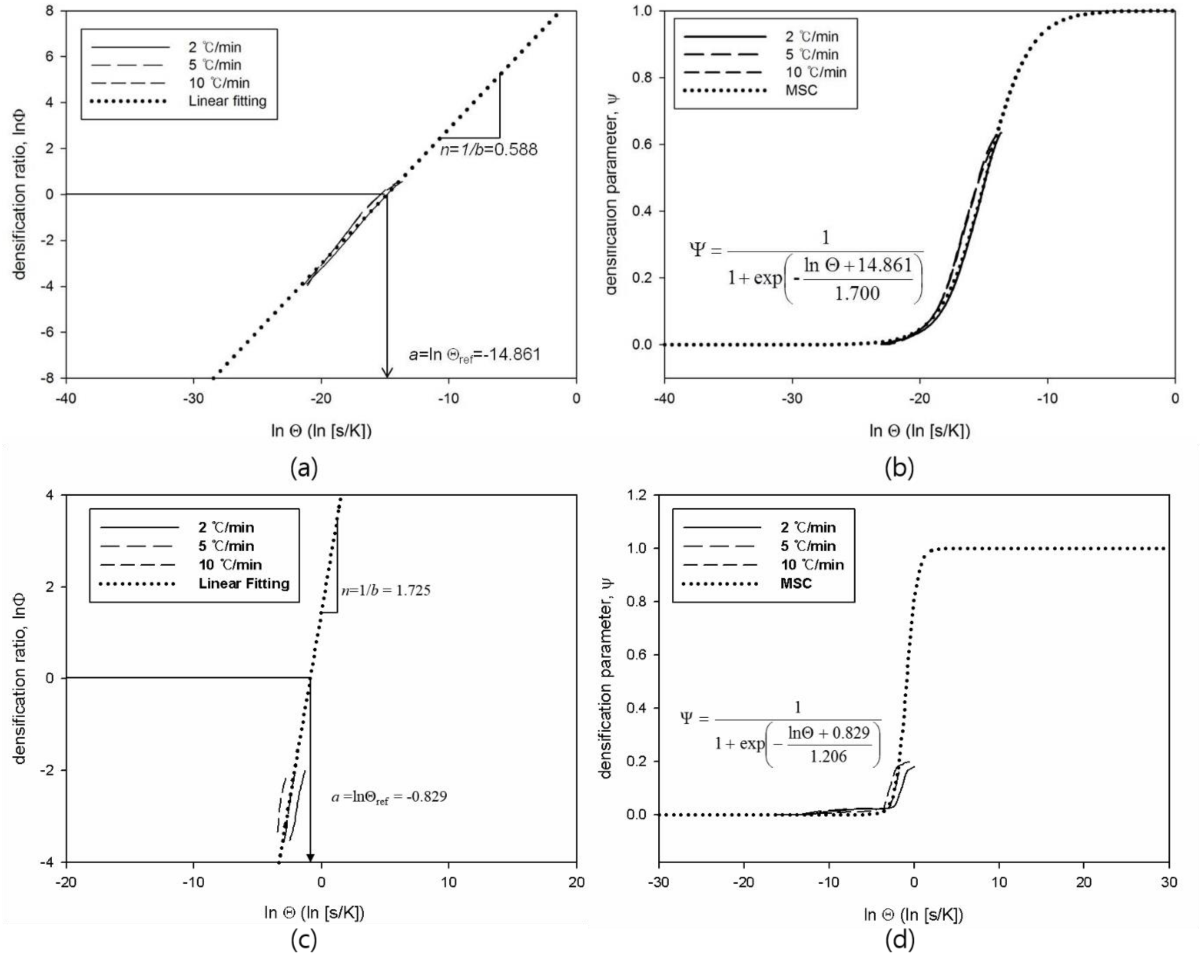

Fig. 2. Linearized form of MSC and Sigmoid function plot, (a, b) W-25wt%Re and (c, d) Re-2W-1Ta.

References

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[2] Blaine DC, Park SJ, German RM. Linearization of Master Sintering Curve. J Am Ceram Soc 2009; 92(7):1403-1409.