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Failure Analysis and Mechanical Reliability of Cast Higher Manganese Silicide

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Abstract

This work focuses on the correlation between microstructure and mechanical properties of higher manganese silicide (HMS). A single crystal HMS ingot was cast from elemental Mn and Si with a nominal composition of $Mn_{15}Si_{26}$. The microstructure of the ingot was characterized, and its fracture strength was evaluated following ASTM C1161 bending test. The correlations between elastic modulus, fracture strain, fracture stress and toughness were studied and Weibull distribution analysis was applied to fracture strength data. Statistical results show a wide distribution in the mechanical prosperities. Fractography reveals the profound effect of the minority MnSi phase on the failure mechanism of HMS. The negative effect of the minority second phase MnSi particles on the mechanical reliability of HMS is highlighted.

Keywords: Thermoelectric; elastic modulus; flexure strength; orientation; failure mechanism; cracks.

1. Introduction

Thermoelectric generator (TEG) is a promising technology to harvest waste heat in different scales, from household applications to large-scale industrial sites [1]. During the last two decades, extensive studies has been carried out aiming to develop new materials or improve the properties of traditional thermoelectric materials [2]. The focus of the majority of the research performed in this field has been to understand electrical properties of thermoelectric materials and to improve their dimensionless figure-of-merit, ZT [3]:

$$ZT = \frac{S^2\sigma}{k}T \qquad (1)$$

where a high figure-of-merit is obtained by maximizing the Seebeck coefficient S and electrical conductivity σ, and minimizing the thermal conductivity k. Among the numerous thermoelectric materials that have been developed, some gained extensive attention and industrial applications because of their superior thermoelectric properties, such as germanium telluride [4], lead telluride [5], bismuth telluride [6,7], Half-Heusler alloys [8] and Skutterudite [9]. Nevertheless, in addition to enhancing ZT, there is also a recognition that widespread use of thermoelectric generators requires the thermoelectric materials to be non-toxic, environmentally friendly, abundant and consequently affordable. For these reasons, significant attention has turned toward silicide thermoelectric materials (namely doped Mg_2Si and HMS). The abundance of the elements used to synthesize silicide thermoelectric materials makes them great candidates, if a large-scale industrial application of TEG were to be adopted. The higher ZT of Mg-based silicide has commanded significant attention relative to the p-type HMS. Nevertheless, a great deal of work has been conducted to study the latter [3,10–12].

$MnSi_{1.75-x}$, commonly known as higher manganese silicide, has a Nowotny Chimney Ladder, where the Mn atoms form the main body of the tetragonal structure (chimney) where the Si atoms form a ladder inside the chimney [13,14]. In this structure, the distance between Mn layers are constant, and the distance between Si layers are related to chemical phase composition [10]. A small variation in