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# Effect of nanoscale boron carbide particle addition on the microstructural evolution and mechanical response of pure magnesium

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ABSTRACT

In this study, the effect of nano-$B_4C$ addition on the microstructural and the mechanical behavior of pure Mg are investigated. Pure Mg-metal reinforced with different amounts of nano-size $B_4C$ particulates were synthesized using the disintegrated melt deposition technique followed by hot extrusion. Microstructural characterization of the developed Mg/x-$B_4C$ composites revealed uniform distribution of nano-$B_4C$ particulates and significant grain refinement. Electron back scattered diffraction (EBSD) analyses showed presence of relatively more recrystallized grains and absence of fiber texture in Mg/$B_4C$ nanocomposites when compared to pure Mg. The evaluation of mechanical properties indicated a significant improvement in tensile properties of the composites. The significant improvement in tensile ductility (~180% increase with respect to pure Mg) is among the highest observed when compared to the pure Mg based nanocomposites existing in the current literature. The superior mechanical properties of the Mg/$B_4C$ nanocomposites are attributed to the uniform distribution of the nanoparticles and the tendency for texture randomization (absence of fiber texture) achieved due to the nano-$B_4C$ addition.



## 1. Introduction

Development of new structural materials for aerospace and automotive applications is driven by the need for light weight components in both cast and wrought forms. In this regard, Mg-based alloys and composites exhibit excellent specific strength and damping capacity. However, their poor deformation characteristics (ductility) at room temperature is due to the low symmetry and the paucity of slip systems in the hexagonal closed packed (HCP) structure of Mg [1–4].

In deformation processing of Mg, the preferred orientation of the crystallographic planes (texture) is considered very important. For example, the strong textures developed as a result of thermo-mechanical (deformation) processes such as extrusion are highly unfavourable for the basal slip (principal slip) to occur, and hence give rise to poor mechanical properties when the testing is carried out parallel to the extrusion direction [4–6]. Literature study reveals numerous attempts being made to improve the deformation behavior of Mg at room temperature [7,8]. In these studies, severe plastic deformation processes are employed to activate the non-basal slip systems/twinning by texture modification. On the other hand, conventional deformation processes employ high temperatures [9,10]. Hence, improving the ductility of Mg-based materials at room temperature is an important criterion, as the improved room temperature ductility can substantially support ease of processing.

Recently, several works have reported favourable modification in texture of secondary processed materials, arising due to composition control/phase formation, giving rise to improved ductility. The dependency of texture and deformation was studied by Stanford and Barnett [11] in wrought Mg-alloys. In this work, they reported the modified deformation behavior of ME10 alloy resulting from the dramatic change in the extrusion texture due to the addition of misch metal. Mackenzie and Pekguleryuz [12] highlighted the influences of alloying additions and processing parameters on the rolling microstructures and textures of magnesium alloys. Several other works [13–15] investigated the effect of alloying elements on the mechanical anisotropy [13], ductility enhancement [14] and microstructural development [15]. In this context, it has been observed that the addition of nanoparticulates such as nano-$Al_2O_3$, nano-ZnO (relatively low volume fractions of <2%) to pure Mg/alloys has resulted in improved mechanical response in the extruded Mg-materials [16,17]. This was attributed to the activation of non-basal slip system that was identified by the change in fracture mode [16] and the reduction in tensile–compression yield asymmetry [17]. However, with regard to such improvements in ductility, no detailed investigation on the influence of micro-texture evolution due to nanoparticle addition in Mg-matrices has been reported so far. On the other hand, while

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**Table 1**
Density and porosity measurements.

| S. No. | Material | Theoretical density (g/cc) | Experimental density (g/cc) | Porosity (%) |
|---|---|---|---|---|
| 1 | Mg | 1.7400 | 1.7397 ± 0.0015 | 0.02 |
| 2 | Mg–0.35$B_4C$ | 1.7427 | 1.7405 ± 0.0008 | 0.04 |
| 3 | Mg–1.04$B_4C$ | 1.7481 | 1.7443 ± 0.0032 | 0.08 |
| 4 | Mg–1.74$B_4C$ | 1.7536 | 1.7507 ± 0.0019 | 0.07 |

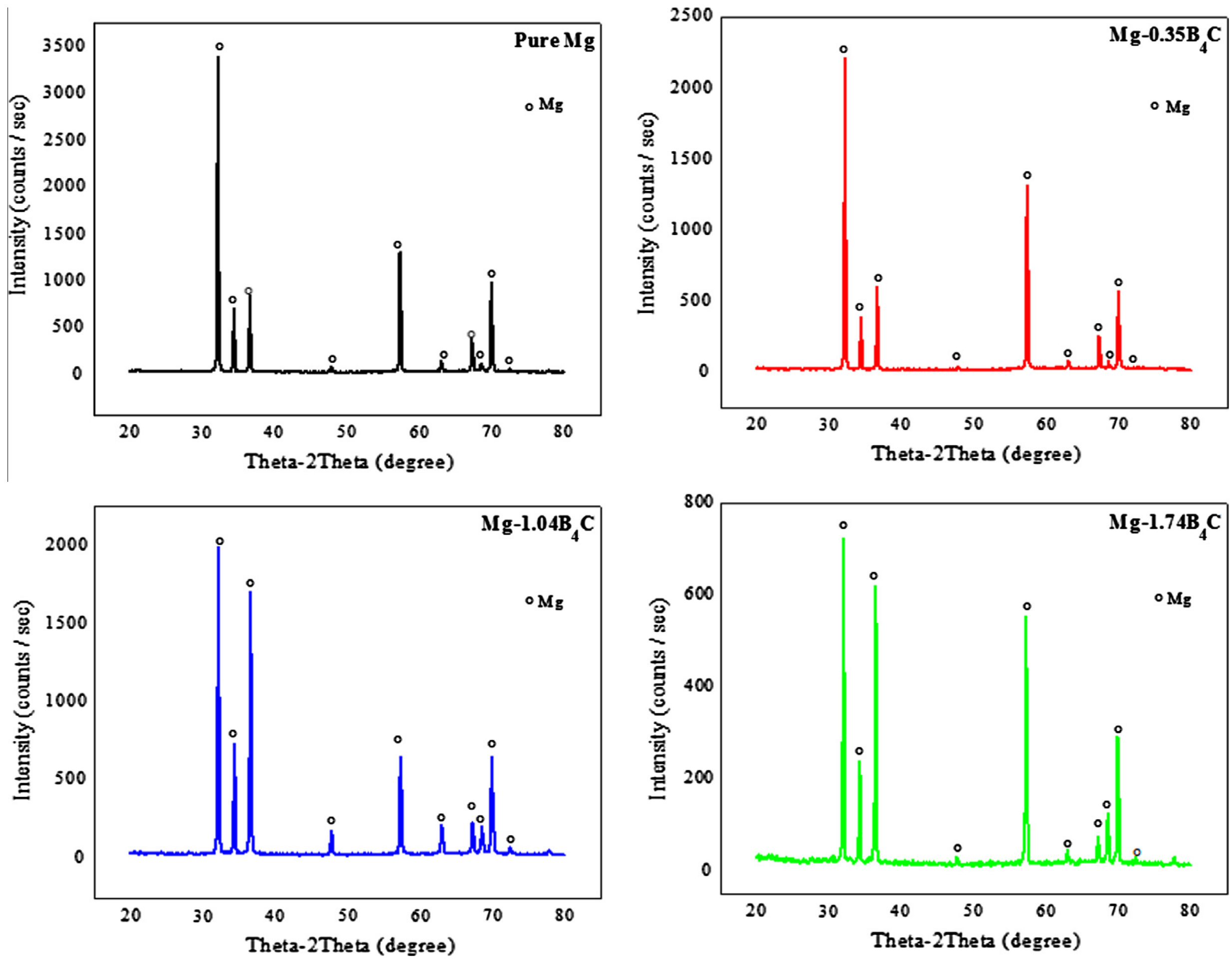


**Fig. 1.** X-ray diffractograms of developed Mg/x-$B_4C$ nanocomposites.

oxide nanoparticulates such as those mentioned above have been widely used as nano reinforcements in Mg alloys, research work on carbide nanoparticle reinforcements (such as SiC, TiC or $B_4C$) are relatively meagre in open literature [18,19].

In the present work, nano-$B_4C$ particles have been incorporated in pure Mg-matrix using liquid-state processing, followed by hot extrusion. The effect of varying volume fractions of nano-$B_4C$ addition on the microstructural and mechanical properties of pure Mg is investigated. Further, the evolution of micro-texture in pure Mg due to the incorporation of nano-$B_4C$ particles has been studied in detail using electron back scattered diffraction (EBSD). Structure-property relationship is used to understand the observed mechanical behavior of the nanocomposites. To the authors' knowledge, the current work is one of the very few studies that investigate the microstructural evolution of Mg-nanocomposites by EBSD methods.

**Table 2**
Results of grain size measurements.

| S. No. | Material | Grain size (μm) |
|---|---|---|
| 1 | Mg | 28 ± 9 |
| 2 | Mg–0.35$B_4C$ | 21 ± 5 |
| 3 | Mg–1.04$B_4C$ | 18 ± 9 |
| 4 | Mg–1.74$B_4C$ | 11 ± 6 |

## 2. Materials and methods

### 2.1. Materials and processing

Pure Mg turnings (ACROS Organics, USA) was used as the matrix material and nano-sized $B_4C$ particulates of particle size ~50 nm (Nabond, Hong Kong) was used as the reinforcement. Mg materials used in this study was synthesized through the liquid metallurgy route based disintegrated melt deposition technique [16]. Mg turnings together with the particulate reinforcements were heated in a graphite crucible to 800 °C in an electrical resistance furnace under inert argon gas protective atmosphere. In order to facilitate the