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Original Research Paper

Characterization and mechanical properties of α-Al_2O_3 particle reinforced aluminium matrix composites, synthesized via uniball magneto-milling and uniaxial hot pressing

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Highlights

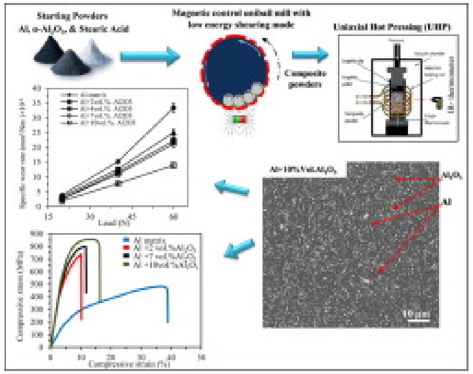
- Near full density composites of aluminium matrix reinforced with α-Al_2O_3 particles.
- Improved mechanical properties were observed for 10vol.%Al_2O_3 particles.

- Homogenous distribution of α-Al_2O_3 particles along the aluminium matrix.
- Improved abrasion wear resistance is observed with increasing volume fraction of α-Al_2O_3.
- Vickers hardnesses increase with increasing α-Al_2O_3.

Abstract

Al-based composite powders containing 2, 4, 7 and 10 volume fraction of α-Al_2O_3 were prepared using the uniball controlled magneto-milling method and were then uniaxially hot pressed at (600±10)°C under 70MPa for 15min. The resulting composites were greater than 99% theoretical density with enhanced mechanical properties. Detailed characterization was performed using: X-ray diffraction, scanning electron microscopy equipped with energy dispersive spectroscopy, electrical conductivity, compression, ultra-micro indentation testing and pin on drum wear testing at ambient temperature. Microstructure-mechanical property correlations were obtained as functions of α-Al_2O_3 volume fraction. It was found that controlled milling resulted in an uniform distribution of the hard α-Al_2O_3 particles within the Al, an acceleration of Al hardening and fracturing, and strain accumulation by the Al matrix. Hardness, strength, wear resistance and electrical resistivity of the monolithic products increased with increasing the volume fraction of α-Al_2O_3 up to 10vol.%. These were: HV=(1.84±0.26)GPa, maximum compressive strength=(845±33)MPa, compressive yield strength=(515±11) MPa. Outcomes were interpreted in light of the structural defects induced by milling, the presence of α-Al_2O_3, and dispersion of iron milling contaminants, with additional effects caused by oxygen introduced during the milling and/or the heat treatment.

Graphical abstract



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Introduction

Aluminium matrix composites (Al-MMCs or AMCs) have been developed and improved upon over the past century. They cover range of demands in aerospace, ground transportation, automotive, electronics and energy sectors [1], [2], [3], [4], [5]. Various reinforced phases in micro and nanoscale including; Al_2O_3, AlN, SiC, TiC, B_4C, SiO_2, BN, CuO, TiB_2, graphene, graphite and intermetallics have been used to reinforce AMCs. These particulate phases create vital changes in the mechanical properties of the pure metals and their alloys [4]. Al_2O_3 is used as a reinforcement material in AMCs due to its low cost, stability at high temperatures, high oxidation resistance, and relatively high chemical stability and inertness [5]. Wear resistance and hardness of AMCs can be improved by Al_2O_3 [6], [7], [8], [9], [10], [11], [12], [13], [14]. It has been found that the breakup of Al_2O_3 into nanoparticles after longer milling times further increases the refinement process, resulting in more uniform dispersions. Al_2O_3 particles tend to enhance particle packing through the dissolution of the soft metal clusters and agglomerates during the milling process [15], [16], [17], [18], [19], [20], [21], [22], [23].

Several processing methods have been developed to synthesize and produce Al-Al_2O_3 micro and nano composites. These including solid state method or powder metallurgy and liquid base with stir casting methods. However, combinations of two or three methods were used for a high quality composite. In solid state milling processes, a process control agent (PCA), and cryo-milling Techniques were used to avoid problems associated with agglomeration and/or cold welding [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47]. The homogeneous dispersion of hard particles within the Al matrix is considered one of the main problems encountered by researchers. AMCs still have some drawbacks including lower yield strength, lower strength and stiffness, poor wear and tear resistance [2], [4]. Al possesses poor wear resistance which can be improved by addition of ceramic hard phase.

In the current investigation, we employed an advanced milling/mixing method, the uniball magneto-ball milling technique [48], [49], [50], in an attempt to prepare uniform precursor powders of $Al+Al_2O_3$, suitable for consolidation using uniaxial hot pressing. This technique involves relatively low energy milling with control over ball-particle impact and particle shearing processes via positioning of external magnets. The method was selected because it can avoid the problem of cold welding of metal particles, common during high energy milling, and has also proved useful for synthesis of homogeneous dispersions of fine particles in a refined metal matrix with lower milling contaminations [48], [49], [50]. Our aims were (i) to produce $Al+Al_2O_3$ precursor powders with refined Al crystallite size and a uniform distribution of Al_2O_3 particles; (ii) to convert these composite powders to high density monolithic samples via uniaxial hot pressing; (iii) to determine optimum parameters for milling and densification, and (iv) to investigate the effects of the volume fraction of α-Al_2O_3 on the physical and the mechanical properties of the monolithic composites. With this in view, different volume fractions (2–10%) and particle size (200 nm) were chosen. Fig. 1 summarizes the synthesis and characterization approach used in purpose of this investigation.

Section snippets

Experimental

Aluminium fine powder of <180 μm particle size and >91.5% purity was obtained from Sigma-Aldrich, and used as the base matrix. The α-Al_2O_3 starting powder (99.9% purity) of submicrometric particles size >200 nm was obtained from Nanostructured and Amorphous Materials, Inc, Huston, USA. Stearic acid powder was used as process control agent and was obtained from Sigma-Aldrich Chemistry. The properties of the starting materials are shown in Table 1. The mechanical milling process was done using a …

Starting materials

Fig. 3 shows indexed XRD and corresponding field emision secondary electron micrographs (FSEM) obtained from the starting aluminium and α-Al_2O_3 powders. The fine Al particles shown in Fig.3b have irregular shape with sharp edges and the submicrometric α-Al_2O_3 particles shown in Fig.3d have irregular shape with rounded edges. Estimates of lattice strain and crystallite size after milling were based on the widths of the Al starting powder peaks. …

X-ray diffraction analysis

Fig. 4 shows XRD patterns obtained from Al+10%Al_2O_3 …

Conclusions

1. Uniball magneto milling process was used successfully to produce composite precursor powders of Al-Al_2O_3 in the presence of stearic acid as process control agent. …
2. Microstructural and XRD results revealed that Al particles fracturing and defect accumulation was improved during milling due to the presence of alumina. …
3. Uniaxial hot pressing was performed to consolidate the composite powders of Al-Al_2O_3 into a dense monolithic cylindrical shape samples (<99% theoretical density) using 70MPa applied …

…

Acknowledgements

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Citation Excerpt :
…The tensile force was applied by gripping it at both ends and load cell was used to identify the amount of force applied. Mechanical parameters of the samples, such as yield and ultimate tensile strength (UTS), were estimated using the stress strain curve acquired from the machine output [48]. For compression test, a CNC cutting machine was used to produce four samples from each AMC cast.…

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> …In the last decades, Al matrix composites (AMCs) have been extensively investigated by a large number of researchers, which are considered to have great potentials in aerospace, automobile, military and construction industries because of their lightweight, high specific strength and stiffness, excellent thermal and electrical conductivity [1–4].…

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> *Citation Excerpt :*
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> …Note that the transformation is accompanied by lattice reconstruction and is irreversible. The final stable α-Al2O3 phase possesses trigonal symmetry with rhombohedral Bravais centring (space group R-3c (No. 167)) [56] and exhibits high hardness, high chemical stability and high oxidation resistance [59,60], which is an excellent reinforcement to strengthen the metal matrix. Microstructural observation via TEM indicates that a clean interface was formed between the α-Al2O3 and HEA matrix with no interfacial defects, which indicates that the in situ α-Al2O3 and the HEA matrix have good wettability and a high interfacial bond strength.…

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