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Synthesis of metal matrix composites and alloys by mechanical alloying: A Review

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Abstract. Mechanical alloying (MA) is one of the most resourceful material synthesis methods. MA includes repeated welding, fracturing and rewelding of powder particles during milling; it leads to uniform distributions of the constituents. In the earlier days MA has been employed to synthesis oxide dispersion strengthened (ODS) alloys, chiefly iron-base and nickel-base alloys. Nowadays it is possible to synthesis equilibrium as well as non-equilibrium structures by MA. Products like wires, bars, rods, billets, aluminides, silicides, carbides, oxides and nitrides are being synthesized via MA. MA has been accepted as one of the non-equilibrium materials synthesis methods. Sometimes it is difficult to mix the metals and non-metal powders through various fabrication techniques, but the above said disadvantage has been overcome by mechanical alloying. From these, Mechanical Alloying has been commented as effective material synthesis technique. This article made an effort to describe the synthesis of metals, alloys, ceramics and their characteristics via mechanical alloying.

1. Introduction

Metal matrix composites finds extensive applications in the field of aerospace, automobile, military, electronic industry in spite of their low density excellent mechanical properties like strength, toughness and corrosion resistance. While preparing the metal matrix composite powders through MA agglomeration or clustering take place between the matrix and reinforcement material will be prevented into addition to that homogenous distribution will occur it results in improved mechanical properties [1]. Mechanical alloying is a powder metallurgy processing method that includes repeated cold welding, fracturing and rewelding of powder particles in a high-energy ball mill. During MA, the transfer of mechanical energy to the powder particles outcomes in introduction of strain into the powder through generation of dislocations and other faults which act as fast distribution routes [2]. Among various synthesis method high energy ball milling is an effective technique to synthesis metal matrix composites. MA is extensively used method to synthesis nano-crystalline materials. By following this route size of the powders can also be reduced [3-4]. It is difficult to synthesis some composites through conventional melt cast process, that type of composites can be easily processed through this route. The homogenous dispersal of reinforcement in the micro and nano composites can

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be improved effectively in the MA process [5]. Traleski Andre Victor et al [6] synthesized Cu-Al-Ni and Cu-Zn-Al alloys by mechanical alloying. Patel et al synthesized Al-Sn-Mg alloy via mechanical alloying and investigated the microstructure and properties of produced alloy [7]. Sadeghian et al fabricated the Al–TiB_2 nanostructured composites via mechanical alloying and reported the X-ray examination and microstructure analysis of the powders via TEM [8]. Developed new Al-Mg-Zrnanocomposites via mechanical alloying and studied the phase evolution by XRD and microstructure analysis by TEM [9].Suryanarayana et al synthesized TiAl–Ti_5Si_3nanocomposites by mechanical alloying and concluded that MA is an ideal method to synthesize nanocomposites in a variety of systems and homogenous distribution can be attained by optimizing the processing conditions [10]. Qing Zhao et al prepared Cu-Cr alloy via mechanical alloying and investigated the effect of milling parameters such as effect of MA on the decomposition temperature of precursor, effect of milling equipment, effect of reducing agent, effect of temperature, effect of process duration [11].Based on the literature survey, this review made an effort to describe the works carried so far in the synthesis of Metal Matrix Composites through Mechanical Alloying Technique.

2. Historical Background

In 1966, Mechanical Alloying technique was developed by Benjamin and co-workers of INCO alloys, USA to synthesis ODS nickel-base alloys for gas turbine modules. Due to remarkable achievement in the production of ODS alloys, later aluminium base alloys has been synthesized through MA for high temperature applications. In the earlier stages of eighties amorphization of intermetallic in yttrium-cobalt and gadolinium-cobalt systems released a novel area that is called as Mechanical Milling (MM). In 1983 amorphization of elemental blends of nickel and niobium was attained. Hence it was named as Mechanical Alloying. Nowadays it is probable to synthesis all equilibrium and non-equilibrium structures by Mechanical Alloying [12].

3. Literature Review

Sivasankaran et al [13] conducted the characterization studies on AA6061-Al_2O_3nanocomposites with different weight percentages (wt% = 0, 4, 8, 12) synthesized through mechanical alloying. Thenanocomposites powders were milled up to 40 h in a planetary ball mill. The synthesized powders were subjected to various characterization studies such as X-ray Diffraction (XRD), Transmission Electron Microscope (TEM) and High Resolution Transmission Electron Microscope (HR-TEM) Scanning Electron Microscope (SEM) analysis. The stress and strain present in the nanocomposite were determined by conducting the X-ray peak broadening analysis. The morphology of the nanocomposites was identified by SEM, TEM and HR-TEM analysis.

JinlingLiuet al [14] synthesized Mg-Al_2O_3 nanocomposites via mechanical alloying. The milling was done for a time period of 20 h. Later structural evolution such as Scanning Electron Microscope (SEM), Energy Dispersive Spectrometry (EDS) and X-ray Diffraction (XRD) was conducted on the milled samples. By conducting the SEM analysis nano structured phase formation was witnessed. Through the X-ray elemental mapping method homogenous dispersal of the phases was confirmed. The SEM and EDS report revealed the homogenous distribution of reinforcement in the matrix. Finally, it has been concluded that nano composites with ultrafine sizes and uniform dispersion of reinforcement particles can be achieved by Mechanical Alloying technique.

Salemiet al [15] synthesized CuNiCoZnAl high entropy alloy by mechanical alloying technique and thermodynamic analysis was conducted on the milled samples. The thermodynamic system parameters such as melting point, mixing enthalpy change, mixing entropy change, atomic size difference, electronegativity difference and valence electron concentration was determined. The results confirmed the development of a FCC solid solution as the stable phase related to amorphous and intermetallic phases.

Jesus Noe Rivera Olvera et al [16] MoZn alloy was manufactured by high-energy mechanical alloying by mixing the pure Mo and Zn powders. The milling was done for 100 h. The characterization studies such as X-ray diffraction (XRD), Scanning Electron Microscope (SEM), High Resolution Transmission Electron Microscope (HR-TEM) was conducted on the milled powders. To analyze the constancy of MA product thermodynamic analysis was conducted using the Miedema model. XRD results displayed the when the milling time reaches the 100 h Mo and Zn raw powders transformed to the MoZn phase. The SEM images clearly exposed the surface morphology of MoZn alloy. The HR-TEM clearly evidentthe formation of a MoZn solid solution nanopowder and local mismatch. Gibbs free energy exposed that the most stable phase is the solid solution related to the amorphous phase at other compositions. By increasing the milling time, the crystallite size of MoZn alloy decreases from 121 to 36.2 nm and the lattice strain increases from 0.085% to 0.276%.

Devesh Kumar et al [17] AlCuCrFeMnW High Entropy Alloy was produced via mechanical alloying method at different milling time. The milling time 10 min, 5 h, 10 h, 15 h, 20 h. The characterization studies such as X-ray diffraction (XRD), Scanning Electron Microscope (SEM), Transmission Electron Microscope (TEM) and EDS Mapping was carried out. The thermodynamic parameters such as Enthalpy (ΔH), Entropy (ΔS), Heat (Q), Melting Temperature (T_M), Compressive Effect of Atomic Size (δ) and Valence Electron Compound was determined. The XRD results show the presence of BCC and FCC phases. At different milling time, crystallite size (C.S.) and lattice strain (L.S.) of the BCC and FCC phases was determined. XRD results confirmed that while increasing the milling crystalline size decreases and lattice strain increases. The SEM images displayed that when increasing the milling time from 5 h to 20 h the size of the powder particles decreased. From the EDS mapping it is evident that after 20 h milling uniform dispersal of all six elemental powders was occurred. The TEM image exposes the size of the powders in nano level. The SAED pattern images exposes the BCC phase (major) and FCC phase (minor) co-occurred in the HEA sample. The thermodynamic properties result shows the formation of simple solid solution.

Murali et al [18] synthesized $AlCoCrCuFeZn_x$ high-entropy alloy by mechanical alloying. The crystal structure and phase formation on AlCoCrCuFeZn high-entropy alloy by varying the Zinc weight percentage at different milling time was characterized using XRD, FESEM with EDS and TEM. The XRD patterns exhibits that at 15 h milling BCC phase was identified and at 20 h milling FCC phase was identified. The SEM image shows the presence of nanoparticles which are clustered into larger elliptical shaped structures. The EDS analysis confirmed the similarity and chemical composition of the high-entropy alloys. The TEM–SAD patterns established thenanocrystallinity with phase formation.

Zebarjad et al [19] investigated the microstructure of $Al\text{-}Al_2O_3$ composites produced through mechanical alloying technique. The $Al\text{-}Al_2O_3$ powders were mixed using horizontal ball mill at different times (20, 30, 75, 150, 270, 330, 450, 600 and 900 min). Then the milled powders were compacted into cylindrical billets. Microstructure examination was made on the produced composites by Scanning Electron Microscope (SEM). The SEM analysis revealed that fine distribution of Al_2O_3 reinforcement with Al matrix has occurred when the milling time increases. Infrared spectroscopy (IR) assessment was made to identify the intermetallic compound formation. The IR result does not show any peak except what be appropriate to alumina.

Varalakshmi et al [20]processed nanocrystallineCuNiCoZnAlTi high entropy alloys by mechanical alloying method at different milling time (0, 5, 10, 15 & 20 h). The characterization studies such as X-ray Diffraction (XRD), Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM) was carried out. The XRD results indicates that while increasing the milling hours crystalline size was reduced and lattice strain was increased. TEM dark field image along with SAD pattern confirm the nanocrystalline nature of the mechanically alloyed equiatomicCuNiCoZnAlTi High Entropy Alloy with BCC structure. The SEM shows some of the elemental powders which were present in the CuNiCoZnAlTi High Entropy Alloy.

Ghods et al [21] synthesized Al–2.5%AlN nanocomposites by mechanical alloying method at different milling hours (5, 10, 15, & 20 h) and studied the effect of particle size on the structure. The characterization studies such as X-ray Diffraction (XRD) and Scanning Electron Microscope (SEM) was conducted on the different hours milled powders. The crystallite size and lattice strain was determined by XRD. The XRD patterns showed that the crystallite size decreases by increasing the milling time and lattice strain increased by increasing the milling time. The SEM image showed that size of the particle reduced gradually while increasing the milling time and uniform dispersion was occurred.

Ahmed A. Al-Jouboriet al [22]produced Fe-C alloys with different compositions Fe-0.8wt.%C and Fe-7 wt.%C at different milling hours (1, 2, 5, 10, 15, 20, 30 h). The characterization studies such as X-ray Diffraction and Scanning Electron Microscope (SEM) was conducted as a function of milling time. From the XRD results it was confirmed that the size of the powder decreased, lattice strain increased and the crystalline size decreased when increasing the milling time. The SEM images revealed the powder particle size reduction and distribution. Mechanically alloyed Fe-7 wt.%C for 30 h directly led to the development of nano scale Fe_3C phase and in the case of the Fe-0.8 wt.%C 30 h led to the development of two phases' α-Fe and Fe_3C.

4. Conclusions

This review article made an effort to shows the way to fabricate different mixture of MMCs with reinforcements and alloys. Numerous methods like stir casting, squeeze casting, investment casting etc followed by so many researchers for the synthesis of particulate reinforced MMCs and alloys. Among that Mechanical Alloying method is the suitable and easiest technique due to its unique features, not only metal matrix composites high entropy alloy can also be processed through this method. The binary to hexanaryequiatomic high entropy alloys can be successfully synthesized by MA. MA has outstanding homogeneity in composition.

5. References

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