

Synthesis, stability and thermal conductivity of Al-Cu nano composite and its water based nanofluid

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Abstract— Synthesis of ultrafine Al-Cu nano composite and its stable dispersion in base fluid is carried out in two step method. Ultrafine powders were prepared by milling elemental Al and Cu powders in a planetary mill. Powder nanocomposite is dispersed in de-ionized water to produce nanofluid by ultrasonication method. The stability of Al-Cu mixture particles in de-ionized water were studied under different pH values by using nano zeta meter. Dislocation density, Particle Size Analysis of the prepare powder was also studied; the results reveal that dispersion stability of Al-Cu ultrafine nano composite in base fluid is better than their fluids of individual Al and Cu particles. This dispersion stability enhances the thermal conductivity and convective heat transfer of nanofluids

Keywords- Nanocomposite, nanofluid, dispersion stability, thermal conductivity, convective heat transfer

I. INTRODUCTION

Nanofluids are engineered by suspending nanoparticles with average sizes below 100 nm in traditional heat transfer fluids such as water, oil, and ethylene glycol. Nanofluids (nanoparticle fluid suspensions) is the term coined by Choi [2] to describe this new class of nanotechnology based heat transfer fluids that exhibit thermal properties superior to those of their host fluids or conventional particle fluid suspensions. Nanofluids may emerge as alternative heat transfer fluids. Heat transfer is one of the most important processes in many industrial and consumer products. [1,2].The concept of nanofluid has attracted considerable interest because of reports of great enhancement of heat transfer [3, 2], mass transfer [4], and wetting and spreading [5] Recent studies indicate that nano-particles can favourably alter thermo physical or transport properties of the base fluid [5,6]. The performance of nanofluid critically depends upon the size and distribution of dispersoids and their ability to remain suspended and chemically un-reacted in the fluid. It is suggested that the uniformity and stability of suspension can be ensured by maintaining appropriate pH, using surface activators or surfactant and employing ultrasonic vibration. In the present study, we have made an approach to synthesize Al, Cu, Al-Cu based nanofluids which can transfer heat more effectively. the primary objectives are to synthesize elemental ultrafine particles Al, Cu and Al-Cu alloy & then preparation of stable dispersion of ultrafine particles in base fluid to develop heat transfer fluids.

II. EXPERIMENTAL METHOD

Synthesis of ultra fine Al, Cu and Al-Cu nanocomposite: the primary objectives are to synthesize elemental ultrafine particles Al, Cu and Al-Cu nanocomposite & then preparation of stable dispersion of particles in nanofluid to develop heat transfer fluids. There are mainly two techniques for synthesizing nanofluids, which are **2.1. Single-step process**

which simultaneously makes and disperses the nanoparticles directly into the base fluids [4-5].

2.2. The two-step method which represents the formation of nanoparticles and subsequent dispersion of the nanoparticles in the base fluid [6, 7]. Many other routes are used for production of ultrapure nanoparticles like physical and chemical vapour deposition [8], co precipitation [9], sonochemical technique [10], sol-gel [11], hydrothermal [12], solution phase method [13], electrochemical synthesis [14], laser ablation [15,].

In the present study nanofluid is produced by using two -step method, at first Milling was carried out in Pulverisette-5 planetary ball mill with steel vials and steel balls to prepare ultrafine particles. Starting materials used for milling were elemental Al & Cu powder with 99% purity for the synthesis of ultrafine Al and Cu particles. Powder particles were milled for 50h in two vials- each containing 35g powder and 350g steel balls. In another set of experiment, 50 atomic wt % of Cu and Al powders were mixed and milled for 50 hours to prepare ultrafine Al-Cu powder. The ball to powder weight ratio (BPR) was 10:1. Milling was conducted at 300 rpm in wet medium (about 50 ml of toluene) to prevent undue oxidation and agglomeration of powder. Steel balls of diameter 10 mm were used for milling. Powder samples were picked up from the vials after selected interval of milling time to see the change in shape and size reduction of powder samples. A very small amount of milled powders (approximately 0.04g) were dispersed in de-ionized water (150 ml) by ultrasonication and subsequently magnetic stirring for about 30 minute each to prepare the desired nanofluid..

III. RESULTS AND DISCUSSIONS

X-Ray Diffraction (XRD): For structural studies, the prepared samples were characterized using laboratory setup of X-ray diffraction with Cu-K α radiation ($\lambda=1.54\text{\AA}$). The XRD patterns of Al-Cu alloy powder particles at different intervals of milling time as shown in fig 1. The XRD pattern of as received powder shows the peaks of Cu and Al, whereas the

final milling product is a single phase nanocrystalline Al-Cu alloy which is clear from the graph. It is evident from the figure that after 10 hours of milling, Al-Cu has started to form. It is also clear from the figure that Bragg peaks for milled product (after 50h of milling) are broad, suggesting accumulation of lattice strain and reduction in crystallite size.

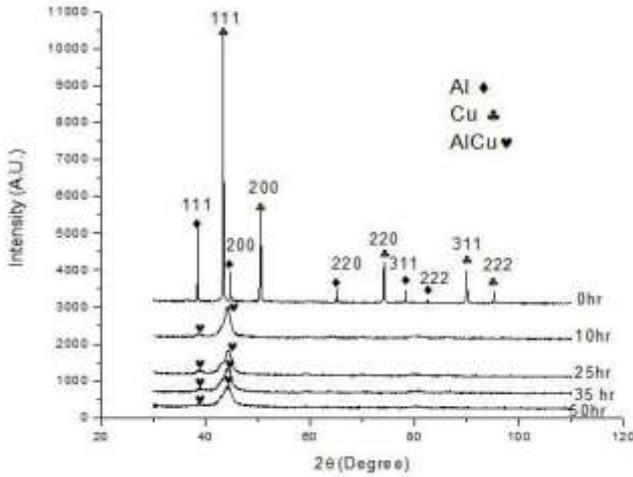


Fig 1. The XRD patterns of Al-Cu powder particles and its composite at different intervals of milling time.

The crystallite size and the lattice strain of the powder measured from the XRD peak broadening is shown as a function of milling time in table 1

Table 1: variation of crystallite size and lattice strain as a function of milling time.

Milling time	Crystallite size (nm)	Lattice strain (%)
10hr	21	0.435
25hr	11	0.815
35hr	9	1.028
50hr	6	1.434

During high energy milling (HEM), the milling energy leads to flattened surfaces. Flattening is also accompanied by an increase in the dislocation density. Dislocation density was assumed to be at least one dislocation per crystallite. Hence dislocation density (N) becomes the inverse square of the crystallite size.

$$N = (Lc)^{-2}$$

The dislocation density increases continuously with milling time as shown in fig. 2. The dislocation density increases due to heavy plastic deformation during HEM.

3.3 Particle Size Analysis:

To study the size reduction of powder during milling, particle size was measured after different milling periods. Firstly, the liquid dispersant containing 500ml of distilled water and 25 ml of sodium hexa metaphosphate was kept in the sample holder. Then the instrument was run keeping ultrasonic displacement at 10.00 micron and pump speed 1800 rpm. Fig. 3 (a) shows the particle size analysis of powder milled for different periods. It is clear from the graph that particle size reduces during milling. It is noted that 80% of the particles are finer than 10 μm after 50 hours of milling. Fig 3(b) shows median size plot of powder milled for different periods. It is observed that median size has been reduced from 22 to 3 μm after 50 hours of milling. In the initial milling period, size reduction rate is very high, whereas as milling progresses size reduction rate decreases and tend to remain constant

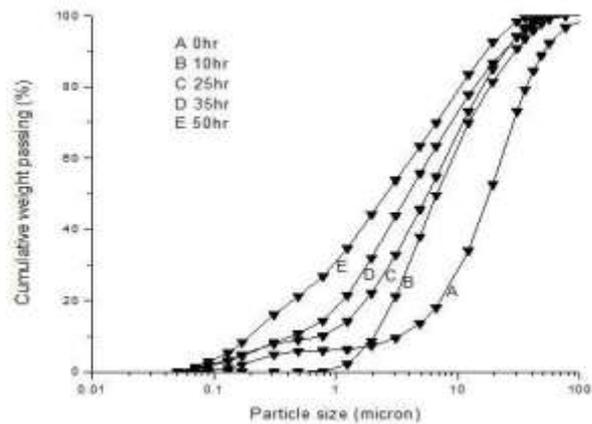
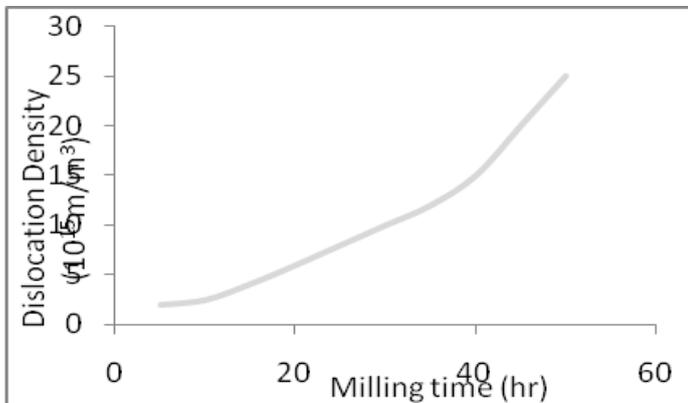


Fig.3(a) shows the particle size distribution of powder at different intervals of milling time



3.2 Dislocation density:

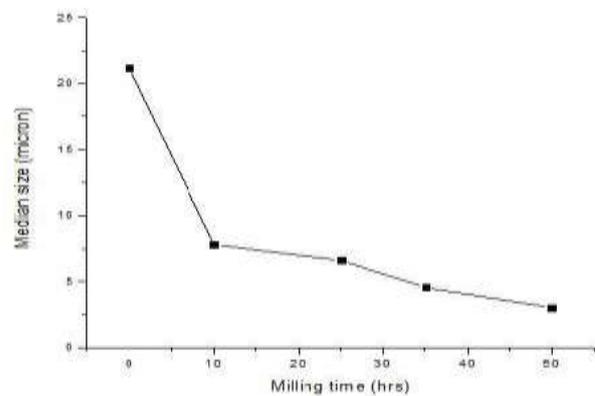


Fig.3 (b) median size of Al-Cu powder particles at different milling time

3.4 Dispersion stability of Al, Cu and Al-Cu ultrafine particles in nanofluid

The stability of Nanofluid was determined by measuring zeta potential values of elemental metallic and alloy powder dispersed in deionized water. However, for measurement of zeta potential, dilute fraction of metallic nano-suspension was selected here. The values of zeta potential ζ can be calculated by the Helmholtz-Smoluchowski equation.

$$\zeta = \mu U / \epsilon$$

Where U is the electrophoretic mobility, and μ , ϵ are the viscosity and the dielectric constant of the liquid in the boundary respectively.

In case of Cu powder particles, the zeta potential is zero at pH= 5.1, which is isoelectric point as shown in Fig 5.1. Therefore the force of electrostatic repulsion between particles is not sufficient to overcome the attraction force between particles and hence the dispersion is least stable. As pH increases or decreases by adding reacting reagent ammonium hydroxide (NH₄OH) or acetic acid respectively, then the particles tend to acquire more charge, so the electrostatic repulsion force between the particles becomes sufficient to prevent attraction and collision between particles caused by Brownian motion. Greater electrostatic force can also lead to more free particles by increasing particle-particle distance so that the distance exceeds the hydrogen bonding range between particles and further reduces the probability of particle coagulation and settling and hence improving the dispersion stability of copper (Cu).

At pH = 2.3, the zeta potential becomes higher; the electrostatic repulsion force between particles is stronger, and the coagulated particles can redisperse through mechanical force. Therefore the dispersion stability of copper (Cu) is best at pH = 2.3 and corresponding zeta potential value is 14.6 mV. If pH-value is less than 2.3, then the zeta potential of particle surface and electrostatic repulsion force decreases due to compression of electrical double layer. Therefore, the suspension exhibits a poorer dispersion. Similarly, for Al powder particles, the zeta potential is zero at pH = 8.9 which is isoelectric point as shown in Fig 5.2 and hence the dispersion is least stable. With decreasing pH value by adding reactant reagent, the stability tends to increase and therefore at pH = 2.5 the zeta potential becomes higher; the electrostatic repulsion force between particles is stronger, and the coagulated particles can redisperse through mechanical force. Therefore the dispersion stability of Al is best at pH=2.5 and corresponding zeta potential value is 54.63 mV. If pH value is less than 2.5, then the zeta potential of particle surface and electrostatic repulsion force decreases due to compression of electrical double layer. Therefore, the suspension exhibits a poorer dispersion.

In case of Al-Cu alloy powder particles, the zeta potential is zero at pH= 9.7, which is isoelectric point as shown in Fig 5.3. Therefore the dispersion stability of Al-Cu alloy is best at pH=10.3 and 4.96 corresponding to zeta potential value of 49 and -27.7 mV. If pH-value is more than 10.3 or less than 4.96, then the zeta potential of particle surface and electrostatic repulsion force decreases due to compression of electrical double layer. Therefore, the suspension exhibits a poorer dispersion.

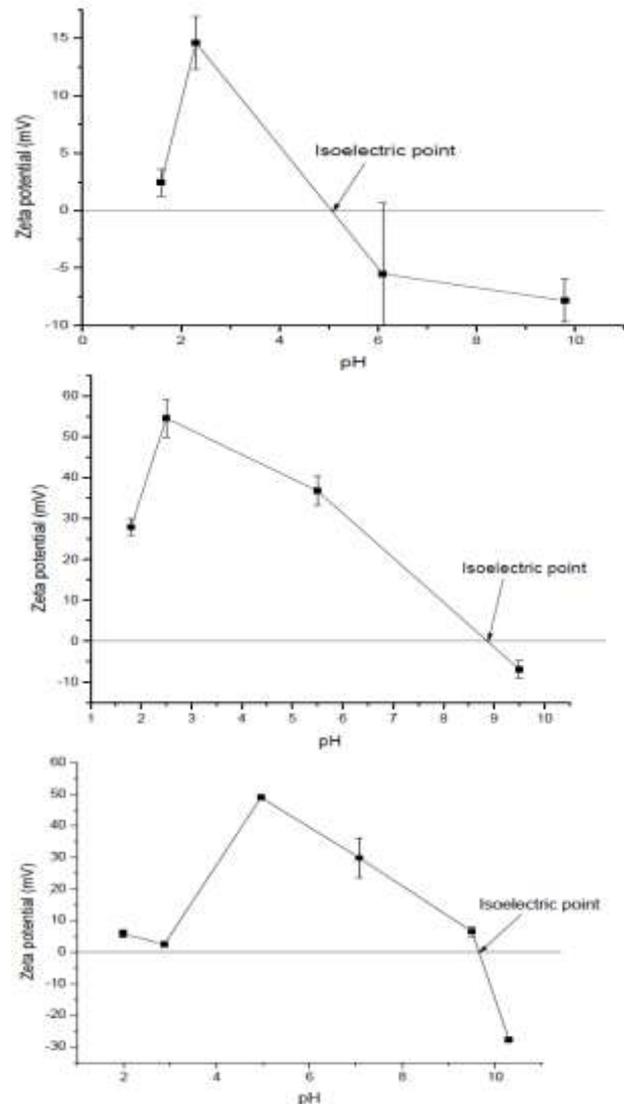


Fig.5 The evolution of zeta potentials of the deionized water-based elemental metallic and alloy powder nanofluids as a function of pH without surfactants. Top left fig 5.1 (Cu); Top right fig5.2 (Al) and Bottom fig5.3 (Al-Cu).

3.5 Thermal Conductivity:

Thermal conductivity and Viscosity data are important to predict the flow and heat transfer in any thermal management application employing convective heat transfer. The investigations on viscosity of nanofluids are relatively less compared to investigations on thermal conductivity of nanofluids. Viscosity describes the internal resistance of a fluid to flow and it is an important property for all thermal applications involving fluids. As these Al-Cu nano particles with aspect ratio >1 provide higher enhancement in thermal conductivity as evident from Hamilton and Crosser model. Hence dispersion of these nanostructures in water will improve the thermal conductivity appreciably.

IV. CONCLUSIONS

It is possible to prepare ultrafine Al-Cu particles through mechanical alloying process by 50 hours of planetary ball milling. The crystallite size decreases and internal strain increases rapidly with milling time up to about 25 hours. With further milling, the crystallite size remains almost constant but

the lattice strain appears to increase. In case of Al-Cu composite, the composite formation starts after 10 hours of milling. The crystallite size decreases and internal strain increases with milling time up to about 50 hours.

It is found from XRD that the crystallite size is around 6 nm and lattice strain is 1.434 % for Al- Cu alloy.

The dispersion of these stable nanostructures in water will improve the thermal conductivity appreciably and heat transfer capacity.

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