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Microstructural, mechanical and tribological behavior of aluminum nitride reinforced copper surface composites fabricated through friction stir processing route

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ABSTRACT

This work focuses on investigating the effect of Aluminum Nitride (AlN) for its 5, 10 and 15 vol% dispersion onto the surface of copper matrix through friction stir processing route. Microstructural observation confirms for the breaking down of grain size thus implying dynamic recrystallization process and also uniform dispersion along with good bonding of AlN particles with copper matrix. Hardness of the developed surface composite exhibits an increasing trend which is supposed to be the effect of dispersed particles and grain size reductions. Tensile tests prove that surface composites yields incremental behavior over strength with rise in AlN vol% even though values were far behind the strength offered by pure copper. Fractured surface micrograph of tensile specimens indicates reduction in ductility of the developed composite with dispersion of AlN particles. Wear resistance showcased a positive inclination with respect to reinforcement increments while the frictional coefficient value also possessed a propensity to increase. The fluctuation of frictional coefficient value diminished with AlN addition mainly because of reduced contact between copper and the rotating counterpart besides carrying away the exerted loads by these AlN particles. Detailed characterization of worn out surface prove that with AlN addition wear rate through adhesion has also reduced significantly.

1. Introduction

Copper metal, well known for its thermal and electrical properties with higher density value showcases low mechanical properties reducing its usage to a greater extent. This disadvantage can be pulled down considerably just by careful selection of suitable reinforcements which help in to strengthen the copper matrix maintaining its highly necessitated electrical and thermal properties. Strengthening of copper matrix is evitable through dispersion of carbides, oxides and borides, thus paving a way for considerable increment in the utility of copper metal matrix for structural application that too with higher range of desirable mechanical and any other relevant properties. From literatures it is generally noticeable that copper matrix with any reinforcement particles has always attracted for a huge attention of many industrial corporate mainly for the sake of improvised hardness, wear resistance, high electrical and thermal properties along with its ability to maintain the coefficient of friction even at high temperatures. Yet again, many such inherent properties of copper metal matrix composites has made it so appropriate for applications such as electric switches, sliding contact material, heat exchangers, marine applications etc [1–4].

Surface composites came into focus as because for certain applications the surface based properties such as hardness, wear resistance, corrosion etc, has to be increased without sacrificing any of the bulk properties owing to the fact that introduction of certain particles into a matrix material reduces its bulk properties such as strength, ductility and toughness. Various processing techniques such as thermal spraying, plasma arc, laser and electron beam based surface alloying has been successfully used by many of the researchers for their studies in order to modify matrix material surface so as to increase wear resistance along with hardness. But as these techniques involve high temperature during process run over, it makes way to certain interfacial reactions to happen which in turn definitely lead to the formations of detrimental phases reducing any of the required properties of surface composites [5–7]. Therefore to overcome these complications during surface modification, a process that works anywhere under the melting point of base matrix material has to be considered; so amongst the availability, Friction Stir Processing (FSP) satisfies the required manufacturing criteria. FSP adapted from Friction Stir Welding (FSW), works under plastic deforming principle of candidate material and dynamically mixing of reinforcements majorly because of frictional heat developed along with stirring action of the tool shoulder and pin

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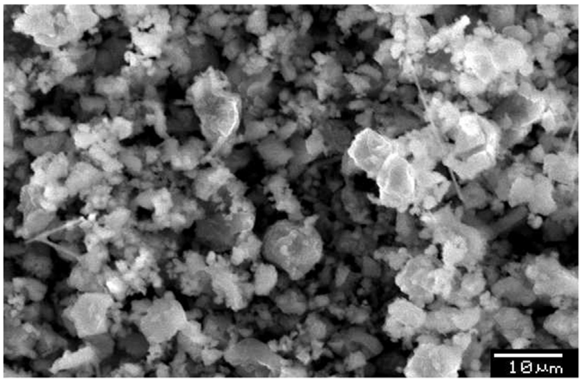

Fig. 1. SEM micrograph for AlN.

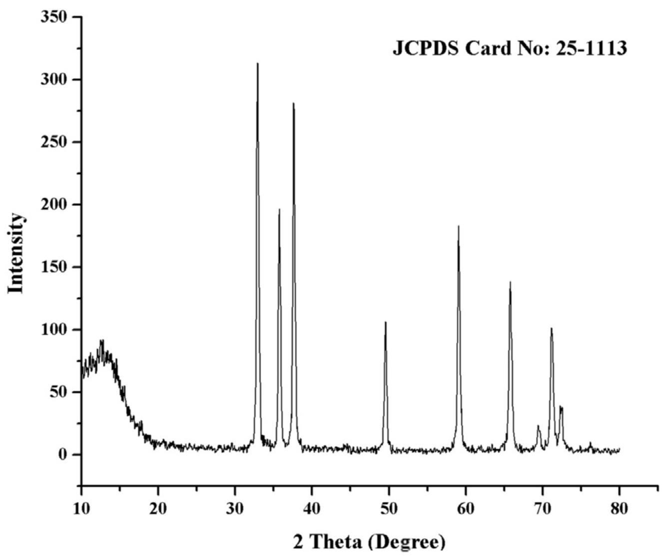

Fig. 2. XRD results for AlN.

[8–12]. Surface composite developed through FSP has exhibited adorable enhancements for all of the tested outcomes inclusive of hardness, strength, ductility and grain refinement [13]. These advantages promised FSP as a major surface modification process and have also made researchers to consider the same in developing aluminium, magnesium, titanium and copper based surface composites.

Development of FSPed copper surface composites have been studied very rarely by researchers worldwide, even though it is likely to posses many of the mandatory properties in superior. Certain studies have showcased copper as one of the promising material and also reported that copper has the ability to exert property increments in major after getting surface modifications through FSP such that of copper nano tube introduction into copper matrix [14]. Even though various studies has only involved in the production of copper based surface composites with oxygen free refractory materials, carbides and borides as reinforcements. On the other hand when employment of advanced reinforcement materials such as nitrides is considered ongoing researches are nil. Nevertheless, nitrides due to their inherency of high hardness, wear resistance and low frictional coefficient, has been well thought-out for various protective metal coatings [15].

Aluminum Nitride (AlN) known for its high thermal conductivity, thermal expansion coefficient, hardness besides being non toxic with superior dielectric properties has been attracted by many of the researchers for exploring newer applications in the field of semiconductors, packages etc [16–18]. These properties of AlN along with its non reactive condition to base metals like aluminum has emerged it out as one of the successful reinforcement helping in enhancing the mechanical and corrosive properties [19–21]. Effective usage of AlN as reinforcement in copper can be sought out as an affirmative replacement in place of currently marketed materials used for various electronic structural applications but however research on AlN reinforced copper metal matrix composites is scarce. What so ever, from available literatures and also by trial FSP experimentations carried over for further execution of this proposed research hypothesis, it could well be reported that for such hard reinforcements, any additions beyond the level of 15 vol% did not yield fulfilled bonding strength.

In lieu considerations of all the above said facets an attempt has been made through this research to reinforce varying vol% of AlN onto the surface of copper matrix, tried out through friction stir processing. The effect of AlN and its vol% increments on mechanical and tribological properties were thoroughly investigated and further evaluated for easy commercialization of this novel development. Grain refinement and dispersion of AlN into copper matrix due to plastic deformation were characterized and analyzed through optical microscope and SEM morphologies.

2. Materials and methods

Commercially available pure copper commonly known as electrolytic copper in the form of plates is used as base material and were cut into specimens of cross-sections 150 mm×50 mm×8 mm. AlN particles used as reinforcement in this study for the sake of surface modification in copper matrix were procured from Sigma Aldrich. SEM micrographs exhibited as Fig. 1 exemplifies acquired AlN

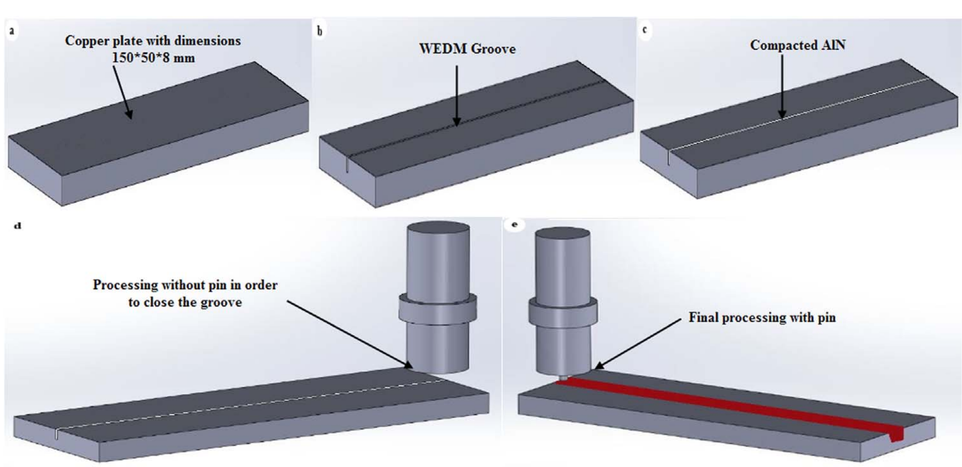

Fig. 3. Diagrammatic view of FSP process (a) Cutting copper plate for required dimensions (b) Groove machining at the center of plate (c) Compacting AlN powder into the groove (d) Processing with pinless tool for groove closure (e) Friction stir processing.