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# Processing of CuTiB2 Composite: A Review

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**Abstract—***Copper based metal matrix composites have wide range of applications in the field of engineering and technology. They are being used as machine housings, heat sinks, substrates, welding electrodes, sliding contacts and motor bushes. The large utility of Cu-based composites is due to the combined effect of their higher mechanical strength and good thermal /electrical conductivity. For improving the interfacial bonding of ceramic reinforcement with the metal matrix, various new processing techniques have been used. This paper aims to discuss different processing techniques used to produce Cu-*$TiB_2$ *composites. The processing routes used in the literature can be classified into three major groups: liquid metallurgy route, powder metallurgy route and combined liquid and powder metallurgy routes. The processing techniques have a direct impact on final microstructure and physical properties of the composites. Therefore, the choice for the best processing route becomes essential for imparting specific properties considering the economic aspects of the processing route as well.*

## 1. INTRODUCTION

Copper infiltrated tungsten alloys are used on a large scale in applications related to space thermal protection system and aircraft propulsion system because Cu-W alloy gives high strength at elevated temperature, high ablation resistance and high resistance to thermal shock [1]. However Cu-W has a disadvantage of having high density (>16 g/cm$^{3)}$ that put cap on its use in some advanced structure, such as rocket motor where a light weight is preferred. Therefore attention was focused on developing new composites with light weight.

Ceramic matrix composites can be a good choice for applications requiring thermal structure because of their light weight, excellent thermal stability and high melting point. The problem of high density with tungsten was get rid of by replacing tungsten with low density ceramic $TiB_2$. In addition to low density (4.52 g/cm$^3$), it has high melting point (3253 K) and high thermal and modest electrical conductivity which makes it perfect choice as reinforcing material for copper[2-3]. When used as reinforcement for copper matrix, $TiB_2$ increase hardness and stiffness of Cu-$TiB_2$ composite on the expense of decreasing modest amount of conductivity. The optimization of various properties of Cu-$TiB_2$composites can be done by varying the degree of reinforcement (%age of $TiB_2$ in copper matrix), which makes the composites suitable for any typical application. However the physical properties and microstructure obtained also depends upon the method of processing the composites. For drawing maximum advantage of the composites various new processing techniques have evolved over last two decades. The major thrust of this overview is to critically consider various processing technique used to fabricate Cu-$TiB_2$ composites.

## 2. METAL MATRIX COMPOSITES-CU-$TIB_2$

Metal matrix composites have many advantages over monolithic metals including higher specific strength, a higher specific modulus, lower coefficients of thermal expansion, better properties at elevated temperatures and better wear resistance [4]. Because of these attributes metal matrix composites (MMCs) are under consideration for a wide range of applications [5]. However, on the other side,disadvantage can be inferiority of their toughness to monolithic metals and they are more costly at present. In comparison with most polymer matrix composites, MMCs have certain superior mechanical properties, namely higher stiffness and transverse strength and, greater compressive and shear strength strengths and better high temperature capabilities. The primary support for these composites has come from the aerospace industry for airframe and spacecraft structures. More recently, the automotive, electronics and recreation industries have been working diligently with these composites. The driving force behind the development of most of the existing composites has been their capability to be designed to provide needed types of material behavior. Discontinuously reinforced metal matrix composites have virtually isotropic properties and lend themselves to metallic design methodologies. The particle and whisker reinforced composites have the advantage of being formable by standard metalworking practices. The major concern in this discussion is of $TiB_2$ reinforced copper composite. This composite is attractive in large number of application requiring high strength, hardness and good thermal/electrical conductivity such as sliding contact, motor bushes, welding electrode etc. The combination of low coefficient of thermal expansion and high thermal conductivity, which it possesses, makes it most suitable choice in applications such as heat sinks, machine housing, substrates, lids etc.

## 3. THE PROCESSING TECHNIQUES

In addition to degree of reinforcement and shape of reinforcement i.e. particulate, platelets, whisker etc. the processing route affects the physical structure and properties obtained by the composites. So in an effort of maximizing the performance and avoiding problems encountered in the use of composites, different processing route have been discovered over time. One general classification of processing route can be based on temperature of process [6]. According to this processing methods can be classified into three categories: liquid metallurgy route, solid metallurgy route and solid-liquid metallurgy route.

## 4. LIQUID METALLURGY ROUTE

In liquid phase process the ceramic reinforced particles are generally incorporated in liquid metal by using various proprietary methods followed by mixing and casting of the resulting metal matrix composites. J.H. Kim et al [7] (2006) in their study "**manufacturing of Cu-TiB2 composites by turbulent in situ mixing process"**fabricated copper matrix composite reinforced by turbulent in situ TiB2 nanoparticle through the reactions of boron and titanium. In the conventional MMCs, the reinforcement was prepared separately before the fabrication of composites. The main problems encountered in the conventional approach were that the scale of the reinforcements phase was limited by the starting powder size, which is typically of the order of micrometer to tens to micrometer and rarely below 1 µm and reinforcing particles were not dispersed uniformly in the metal matrix. But in "in situ processing" the reinforcing phase are formed by the reaction of titanium and boron. The turbulent in situ formed $TiB_2$ particles, which had a size of from 50 to 200 nm, exhibited a homogenous dispersion in the copper matrix. $TiB_2$ particle size decreased in the direction of wheel side from free surface. The hardness and Young's modulus of Cu–$TiB_2$ composite were improved with the increase of cooling rate.

J. Hashim et al [8] (1999) in their study "**production by stir casting method**" discussedthat one factor which has restricted the widespread use of MMCs has been their relatively high cost. This is mostly related to the expensive processing techniques used currently to produce high quality composites. The relatively low cost stir casting technique was evaluated for use in the production of silicon carbide/aluminum alloy MMCs. The technical difficulties associated with attaining a uniform distribution of reinforcement, good wettability between substances, and a low porosity material were presented and discussed.

Jongsang Lee et al [9] (2000) in "**Microstructure and properties of titanium boride dispersed Cu alloys fabricated by spray forming"** manufactured dispersion strengthened Cu-alloy by conventional spray forming and also by reactive spraying followed by hot extrusion spray deposited billets. The relationship between microstructure and mechanical properties of the Cu composite was examined for conventional spray forming and reactive spray forming by using transmission electron microscopy (TEM), scanning electron microscopy (SEM), optical microscopy (OM) and tensile testing. A comparison was made between microstructure and mechanical properties obtained. The results showed that the size of the dispersed particle in reactive spray forming was much finer than that of obtained in conventional spray forming. The yield strength also improved considerably in reactive spray forming and this increase in yield strength can be largely attributed to fine nanoscale dispersoids, which demonstrated a strong feasibility of manufacturing DS copper alloys with high strength by reactive spray forming.

## 5. SOLID METALLURGY ROUTE

For processing Cu-$TiB_2$ by solid metallurgy route, a lot of advanced development has been taking place over last 20 years. Two main methods ofsolid processing are powder metallurgy route and high energy rate processing [10]. The powder metallurgy route provides scope for avoiding the problems with conventional casting processes. In terms of microstructural requirement, the powder metallurgy route is superior in view of rapid solidification experienced by powder. Casting processes are good because they are less costly but it is very difficult to control the microstructure and dispersion of reinforcement. These problems can easily be got away in powder metallurgy. Another approach which has been successfully used in consolidation of quenched powder is the high energy rate processing. In this approach, the consolidation of ceramic matrix composites is done by application of high energy for a short period of time. A discussion on powder metallurgy processing and advancement made in it over time can be made as follows-

P. YIH and D.D.L. CHUNG [11-12] (1997) in their study titled as "**titanium diboride copper-matrix composites**" manufactured Cu-$TiB_2$ composites by hot pressing using two methods namely admixture method and coated filler method. In admixture method copper powder and $TiB_2$ platelets were simply mixed but in coated filler method the $TiB_2$ platelets were initially coated with copper and then optionally mixed with copper powder. The microstructure, mechanical properties and thermal/mechanical properties were examined by varying the degree of reinforcements from 15% to 60%. In a latter investigation a comparison was also made between the properties obtained by admixture and copper methods. The results of the study shows that microstructure and useful mechanical/electrical properties obtained in coated filler method were better than that in admixture method.

Hong Changqing et al [13] (2003) in their study titled as "**Influence of hot pressing on microstructure and mechanical properties of combustion synthesized $TiB_2$–Cu–Ni composite**" prepared $TiB_2$-Cu-N ceramic metallic composites with relative density of about 90%. Mechanical properties of composites were improved by hot pressing of conducted on 1200, 1250 and $1300^0$ C respectively. After hot processing TiB2ceramic grains of the combustion synthesized $TiB_2$–40Cu–8Ni composite transformed from near equal axis like shape to rod-like shape. The change of morphology is not realized through elastic and plastic deformation, but due to diffusion growth of $TiB_2$ in high temperature. Influence of hot-pressing pressure on the morphology and microstructure of the composite is not remarkable, but partial shear force drives the gliding or wheeling of $TiB_2$ particle, which is favorable to eliminate micro-pores.

With rapid development of aircraft and space vehicles it has become necessary to develop materials which can withstand severe environmental condition such as ultra-high temperature, space protection system and large gradients in aircraft propulsion system. Resistance to thermal shock is property of materials which can withstand such severe conditions. **Jiecai Han, Changqing Hong et al**[14] in 2005 conducted a study to examine the thermal shock behavior of Cu-$TiB_2$ composites. By using copper powder, elemental titanium and boron, TiB2–Cu interpenetrating phase composite materials (IPC) were prepared by combustion synthesis. Thermal shock behavior of TiB2– Cu IPCs is also investigated using a plasma torch arc heater. No crack was found on the thermal shock surface of the TiB2–Cu IPCs.

Grain size and shape has a direct impact on the mechanical and electrical properties of the materials. For the improvement and optimization of Cu-$TiB_2$ composites for electrical use, the refinement of the grains is done with the help of a process called mechanical alloying. In mechanical alloying the mixture of Cu and $TiB_2$ is milled in high energy planetary ball mill at high speed for a specified period of time. M. Lo´pez [15] (2005) et al a study titled as "**Performance and characterization of dispersion strengthened Cu–$TiB_2$ composite for electrical use"** conducted experiment for fabricating the Cu-$TiB_2$ composites in two stages: (a) mechanical alloying in a planetary mill of high energy (b) consolidation by hot uniaxial pressure followed by hot rolling. The high energy ball milling induces high impact on the ceramic, due to this the wettability and stability of ceramics in liquid metal improved considerably which cause the better microstructure of composite and electrical properties are improved. In this study M. Lo´pez et al performed milling of copper based alloy with 1% and 2% volume of $TiB_2$ for a time span of 12 hr. and 36 hr. The amount and distribution of dispersed ceramic affect brittleness and the mechanical properties of Cu–$TiB_2$ composites. The $TiB_2$ alloy produced by 36 h of MA, shows greater hardness and tensile strength than the ones produced in 12 h. The resulting compacts consist mostly of equi-axed $TiB_2$ grains with an average diameter of 0.6 Am for 36 h. It means the time period of the milling cause a positive effect on the properties and refinement and better dispersion of $TiB_2$ particle in Cu matrix.

In G.S. Wang et al [16] (2013) A Cu matrix composite with 5vol% TiB2 particles produced by powder metallurgy was subjected to equal channel angular pressing (ECAP) for 4 passes at 513K to enhance the strength of the Cu matrix through grain refinement. The introduction of TiB2 particles with the particle spacing comparable with particle size increased the effective strain and led to homogeneous deformation structure with low recrystallization nucleation propensity.

Amit S. Sharma et al [17] (2013). In the development of materials with better tribological properties, it is generally perceived that the addition of softer phase will yield better frictional behavior. Fretting wear study were performed on Cu–10wt%TiB2 and Cu–10wt%TiB2–10wt%Pb composites sintered using spark plasma sintering (SPS) technique. It was reported that the addition of softer phase i.e.10wt % Pb to Cu–10wt%TiB2 composites has not resulted in the lowering of the coefficient of friction (COF). The combination of steady state COF (0.6) and wear rate (10_3 mm3/N-m) was measured and such properties are even better than that obtained with TiB2 coatings reported in the literature.

The preservation of the desired combination ofmechanical/tribologicalpropertiesinultrafine grained materials presents importantchallengesinthe field ofbulkmetalliccomposites [18].Inordertoaddressthis aspect, thepresentworkdemonstrateshowonecanachieveagoodcombinationofhardnessandwear resistance inCu–Pb–TiB2 composites, consolidatedbysparkplasmasinteringatlowtemperatures (o500 1C). Transmissionelectronmicroscope(TEM)studiesrevealultrafine grainsofCu(100–400nm)with coarserTiB2 particles (1–2µm) alongwith fine scalePbdispersoidattriplejunctionsoratthegrain boundaries ofCu.Importantly,ahighhardnessofaround2.2GPaandrelativedensityofcloseto90% relativedensityhavebeenachievedforCu–15wt%TiB2–10wt%Pbcomposite.Suchproperty combination hasneverbeenreportedforanyCu-based Nano composite,byconventionalprocessing route.

## 6. LIQUID-SOLID (TWO PHASE) METALLURGY ROUTE

In two phase process two generally known and applied methods are: Osprey deposition and Rheocasting [19]. In osprey deposition the reinforcement particles are introduced in the molten metal/alloy and gas atomized by inert gas jets. This is them sprayed and collected on a substrate reinforcing metal matrix billets. This process is combination of blending and consolidation of powder metallurgy.

In rheocasting the ceramic particles are introduced into a metallic alloy within the solid-liquid range and then agitated to form viscous slurry. This is then solidified to form final product.

Jinyong ZHANG et al [20], (2005) performed the fabrication Cu-$TiB_2$ composites by "**in situ combusting synthesis technology, SHS**". In this experiment the chemically pure powder of Ti, B and Cu were taken. The atomic ratio of Ti and B were kept as 1:2. The powders were dry milled for 6 hr. with different contents of Cu in a plastic bottle with agate ball medium. The combustion temperature and combustion wave propagating process were recorded by a fast temperature & image recording system. According to the combusting characters of the system, technology way of SHS/QP was then determined.

The characteristics of Ti-$B_{-x}$ Cu SHS were examined in detail such as product phase, grain size and combustion temperature. It was found that increase in Cu content results in changing the combustion temperature and the combustion wave propagating velocity. It was also clear from the results that Cu above 25% is not appropriate for densification and under this technology compact Cu-$TiB_2$ composite with relative density over 97% of the theoretical density were manufactured.

## 7. CONCLUSION

The use of Cu-$TiB_2$ composites, in various areas of engineering applications includes thermal structure of the space vehicle and many other application requiring high mechanical strength and hardness along with good electrical and thermal properties,have attracted the attention of researcher in the recent past. To maximize its performance in different applications various experiments have been performed by researchers. Experiments including the variation of quantity of reinforcement and refining method has been so far used. The factor which has so far restricted the use of composites is their high cost. The cost of the composites depends a lot on the manufacturing methods. So in effort of economizing the fabrication of composites various new techniques have been developed and the further studies also required concentrating on the economic aspects of the process so that the composites can replace other less benefited materials.

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