Mechanical And Thermal Properties Of Copper Cordierite Ceramic Matrix Composites

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ABSTRACT

A raw material batch mixture was used for forming the matrix composite (cordierite) ceramic includes the Iraqi clay (Kaolin Duekha), Alumina and Talc. Copper / cordierite (Cu/Cor) composites were prepared from Iraqi cordierite as matrix materials reinforced with different percentage ratios (10, 20, 30, and 40) Cu wt%. The temperatures of sintering are (700,800) °C and the time of treatment at any temperature is (1, 2) hours respectively. The effect of Cu content on compression strength, hardness, and thermal conductivity has been investigated. The high conductivity was attributed to the formation of continuous copper network in composite, while the high compression strength of 167.8 Mpa indicating a homogeneous dispersion of copper in Iraqi cordierite ceramic matrix composite led to a notable improvement in the mechanical properties of the composite.

Keywords: Metal / Ceramic Matrix Composites (CMCs), Cordierite, Mechanical Properties.

1. INTRODUCTION

The recent evolution in different engineering applications scopes and many of our modern technologies demands, require using new types of materials with special characteristics have been developed, which suit different applications and solve many problems which face traditional materials like metals, alloys, ceramics, and polymeric materials[1]. These materials are characterized by the ability to combine several different characteristics through composing between two materials or more which have different characteristics, these are called composite materials [2]. Good electrical and thermal conductivities, as well as chemical stability, make copper an attractive material for a wide range of applications, such as heat exchanges, make-and-make electric switches and sliding contact materials [3,4]. Ceramic matrix composite, cordierite (2MgO.2Al2O3.5SiO2), possesses a unique combination of several characteristics as thermal shock resistance due to a low thermal expansion coefficient, porosity and pore size distribution and sufficient refractoriness because the melting point exceeds 1450 °C. Ceramic matrix have wide range of applications as electrical insulators, low – expansion refractory’s and packing materials [5]. Much recent research has focused on using commercial cordierite as a matrix composite reinforced with metals (CMCs) [6]. CMC5 containing copper metal as reinforcements have attracted both scientific and industrial interest. Particles reinforced CMC5 combine the ceramic properties of the matrix (high strength and modules) with the metallic properties of the reinforcement (good ductility and toughness), leading to better mechanical properties and higher temperature capabilities [7]. Many works have been made to synthesis metal reinforced commercial ceramic composite focusing on improving their mechanical, electrical and thermal properties. According to our knowledge, there has been no report on low-cost preparation of Iraqi cordierite ceramic to be used in composite. Hence in the present work, we have studied influence of addition different percentage ratios of copper metal reinforced to Iraqi cordierite as ceramic matrix composite through powder metallurgy technique and the effect of heat treatment temperature in different times have been investigated for structural, mechanical and thermal properties.

2. EXPERIMENTAL PROCEDURES

In this work, Iraqi Kaolin Duekha, Alumina (Al2O3) and Talc with purity (99.9%) supplied by Merck company were used as the starting material for preparation cordierite ceramic according to the ratios (7.57wt%Alumina, 49.70wt%Kaolin Duekha, 42.79wt%Talc). Mixing the powders, then heating at 80 °C in the water bath to avoid the aggregation, dried at 100 °C followed by grinding then dry ball-milling for 12 hours. Fine powder was granulated with 1wt% polyvinyl alcohol (PVA), and pressed 4g of each sample in a steel die (of 20mm in diameter and about 5mm in thickness) at 100Mpa for one minute, using electrical press (model (38888.4D10A00,made in USA manufactured by CARVER-Inc). The compacted samples were sintered by electric Muffle Furnace (Nabertherm HT62Ti7 ORz made in Germany) at heating rate of 7 °C/min up to the sintering temperature (1350) °C and held at that temperature for two hours. After the sintering process, the samples were grinded then milled to get fine cordierite powder with particle size less than 25μm. The Cu / Cor composite were prepared from a mixture of the percentages weights -: (0% Cu / 100% Cor, 10% Cu / 90% Cor, 20% Cu / 80% Cor, 30% Cu / 70% Cor, 40% Cu / 60% Cor), are poured into a container of the mixing machine (made in England) for 6 hours. After mixing, each mixture was sieved through a
sieve of (500 mesh), certain weight 4g for each sample pressed in steel die with 100 Mpa for two minutes. The samples were heat treated with temperatures of (700,800) °C, the time of heat treatment at any temperature is (1, 2) hours respectively as satiability time, and in sintering composite an inert gas (argon) of protective system from atmospheric oxygen is always used to prevent pollution and oxidation of samples. The microstructure of produced samples were investigated using (SEM). The hardness values(HV) was tested with a Vickers diamond indenter, by using "Digital Micro hardness tester VHS 1000". The compression strength (σf) was evaluated by using diametrical strength method. Moreover, the Lee's method was used to measure thermal conductivity (K).

3. RESULTS AND DISCUSSION

Scanning Electron Microscopy (SEM)
The SEM micrographs of both cordierite and (Cu/Cor) composites reinforced with different copper content (10, 20, 30 and 40) wt % and sintered at (700,800) °C for 2 hours respectively are shown in Figs (1,2). SEM micrograph of cordierite ceramic shows wide particle size distribution contains small porous, which is favorable for infiltrating copper particles into the porous during the heat treatment of Cu/Cor composite at 700, 800 °C for 2 hours respectively. It is obvious from the results of microstructure of (Cu/Cor) composite that increasing the amount of copper content gradually up to 40 wt % and elevated the heat treatment temperature from 700 °C to 800 °C have an important effect on diffusion of copper metal into the cordierite ceramic [5]. Homogenous distribution of the copper metal into the cordierite ceramic matrix, formation of continuous copper network in 30,40 wt % Cu/Cor composites heat treated at 800 °C for 2 hours leads to prepare composite material with good thermal and mechanical properties [8].
(1) SEM photographs of the composite samples reinforced with different copper contents heat treated at 700 °C for 2 hours:

a) 0 wt % Cu, b) 10 wt % Cu, c) 20 wt % Cu, d) 30 wt % Cu, e) 40 wt % Cu.

(2) SEM photographs of the composite samples reinforced with different copper contents heat treated at 800 °C for 2 hours:

a) 0 wt % Cu, b) 10 wt % Cu, c) 20 wt % Cu, d) 30 wt % Cu, e) 40 wt % Cu.

Mechanical properties

Hardness (Hv)

Hardness was calculated for cordierite and Cu/Cor composites samples with various reinforced content of copper heat treated at (700,800) °C for (1,2) hours respectively. The results of hardness for all samples are illustrated in Fig (3). The presence of copper in cordierite decreases the hardness in comparison with the untreated sample (without copper), this reduction attributed to the low hardness and high ductility of copper [9]. The hardness decreases highly with addition of 10 wt% of copper because of addition of the soft metal phase to the hard ceramic phase and slightly
stable decreases in (20,30,40) wt% copper respectively. Also, Fig (3) shows the effect of heat treatment at 800 °C leads to reduction the hardness more than 700 °C and in 2 hours more than one hour.

**Fig (3) :** Hardness as a function of percentage amount of copper in composite material at a) heat treatment700 °C for (1, 2) hours . b) heat treatment800 °C for (1, 2) hours

**Compression strength (σf)**
Compression strength was calculated from the data, for cordierite and Cu/Cor composites samples heat treated at (700,800) °C for (1,2) hours respectively and the result shown in Fig (4). Addition of copper content to Cordierite ceramic matrix causes an increases in compressive strength and, noticeably higher value at 800 °C than 700 °C, whereas the increase is significant for 2 hours than 1 hour. Also addition of copper content to 40wt% Show significant increase in compressive strength than (30, 20, 10) wt% of copper content as shown in Fig (4). The addition of copper particles to the cordierite ceramic matrix increases the dislocation density at the particles matrix interfaces [10]. This is because of the differences in coefficient of thermal expansion (CTE) between the hard and brittle ceramic matrix and the soft and ductile reinforcing particles of copper, elastic and plastic incompatibility between the matrix and reinforcement, which leads to interaction stress [11]. The compression strength of (Cu/Cor) composite was found to be 167.8 Mpa as a maximum value at heat treatment in 800 °C for 2 hours. This remarkable strengthening of the composite may be due to uniform homogeneous, dispersion and better interfacial strength between copper and cordierite ceramic. Hence there is an improvement in the strength of the cordierite ceramic reinforced with copper particles.

**Fig (4) :** Compression strength as a function of percentage amount of copper in composite material at : a) heat treatment 700 °C for (1, 2) hours , b) heat treatment 800 °C for (1, 2) hours.

**Thermal conductivity:**
Thermal conductivity at room temperature for cordierite and different of Cu/Cor composites was determined for many factors such as , the thermal conductivities of the constituent phases, the percentage amount of the reinforcement , distribution of the constituent phases, and interaction between phases[12]. The results of thermal conductivity investigations is show in Fig (5), which is depend on the content of Cu Wt% in Composite, the temperature of heat

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**Fig (5) :** Thermal conductivity as a function of percentage amount of copper in composite material at: a) heat treatment 700 °C for (1, 2) hours , b) heat treatment 800 °C for (1, 2) hours.
treatment and time of treatment. The existence of continuous copper distribution network strongly affects the thermal conductivity of Cu/Cor composite, leading to good thermal conductivity for 40Wt% Cu/Cor composite heat treated at 800 °C for 2 hours more than that for all the other prepared Cu/Cor composite samples. In this work, thermal conductivity of cordierite was 0.83 W/m.k increased to 2.34 W/m.k for cordierite matrix containing 40 wt % Cu as reinforcements, heat treated at 800 °C for 2 hours, since with increases copper content the pores closed that enable ceramic to transfer heat and increasing thermal conductivity [13].

![Graph](image1)

**Figure (5) :** Thermal conductivity as a function of percentage amount of copper in composite material at:

(a) heat treated 700 °C for (1,2) hours,  
(b) heat treated 800 °C for (1,2) hours.

The results of all the measured properties are listed in Table 1.

<table>
<thead>
<tr>
<th>Material (Wt%Cu)</th>
<th>700 °C</th>
<th>Hardness (Hv)</th>
<th>Compression strength (cf)</th>
<th>Thermal conductivity (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1hr</td>
<td>2hrs</td>
<td>1hr</td>
<td>2hrs</td>
</tr>
<tr>
<td>0wt%Cu</td>
<td>0.365</td>
<td>0.350</td>
<td>38</td>
<td>48.17</td>
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<tr>
<td>10wt%Cu</td>
<td>0.29</td>
<td>0.19</td>
<td>61.4</td>
<td>68.2</td>
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<tr>
<td>20wt%Cu</td>
<td>0.21</td>
<td>0.179</td>
<td>101</td>
<td>123.9</td>
</tr>
<tr>
<td>30wt%Cu</td>
<td>0.197</td>
<td>0.177</td>
<td>126.2</td>
<td>148.6</td>
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<tr>
<td>40wt%Cu</td>
<td>0.186</td>
<td>0.169</td>
<td>134.9</td>
<td>161.3</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Material (Wt%Cu)</th>
<th>800 °C</th>
<th>Hardness (Hv)</th>
<th>Compression strength (cf)</th>
<th>Thermal conductivity (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1hr</td>
<td>2hrs</td>
<td>1hr</td>
<td>2hrs</td>
</tr>
<tr>
<td>0wt%Cu</td>
<td>0.335</td>
<td>0.322</td>
<td>41.41</td>
<td>54.1</td>
</tr>
<tr>
<td>10wt%Cu</td>
<td>0.206</td>
<td>0.189</td>
<td>98.2</td>
<td>111.7</td>
</tr>
<tr>
<td>20wt%Cu</td>
<td>0.189</td>
<td>0.167</td>
<td>122.4</td>
<td>126.9</td>
</tr>
<tr>
<td>30wt%Cu</td>
<td>0.181</td>
<td>0.157</td>
<td>139.9</td>
<td>154.1</td>
</tr>
<tr>
<td>40wt%Cu</td>
<td>0.179</td>
<td>0.151</td>
<td>148.8</td>
<td>167.8</td>
</tr>
</tbody>
</table>

**4. CONCLUSIONS**

From this work, it has been found that, addition copper to Iraqi cordierite ceramic leads to produced dense ceramic matrix composites (CMCS) were successfully obtained by heat treated at 800 °C for 2 hours. With increasing the addition of copper up to 40wt% both the compression strength and thermal conductivity of cordierite are effectively improved while the hardness decreases. Thus, Cu is proven to be a promising reinforcement ceramic.
REFERENCES