# Study Of The Structural Properties Of Al-Zn Compounds Manufactured By Powder Technology And Copper-Reinforced

**Sukaina Iskandar Yusuf**, Sabri Jasim Mohammad, Mohsin Hasan Ali

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## ABSTRACT

Due to the importance of aluminium compounds in many industrial fields, therefore, in this study, copper-reinforced (Al-Zn) compounds were prepared in different proportions (0%, 0.4%, 1.2%, and 2%), using the powder technique. The structural properties of the compounds under study were investigated using XRD and EDS tests at room temperature. It was found through the XRD results that the samples were polycrystalline (cubic, tetragonal, monoclinic, and hexagonal). The results of the crystallinity analysis showed that sample (Al-Zn-(0%)Cu) was (12.73%) crystallized, sample (Al-Zn-(0.4%)Cu) was (32.125%) crystallized, sample (Al-Zn-(1.2%)Cu) was (42.771%) crystallized, and sample (Al-Zn-(2%)Cu) was (50.179%) crystallized. Theoretical density of the phases was determined for each sample using independent calculations, taking into consideration some factors such as variations in atomic mass, the number of atoms of the constituent elements, and the size of the unit cell.

## Article Info

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**Keywords:** Powder technology, Reinforcement, (Al-Zn) composite, Structural analysis, Crystallinity.

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ملاحظة: الاهمية لمكونات الألومنيوم في العديد من المجالات الصناعية، لذلك تم في هذه الدراسة، تحضير مركبات (Al-Zn) المصنعة بتقنية المساحيق، وتم دراسة الخصائص التركيبية للمركبات باستخدام تقنيات XRD وEDS عند درجة حرارة الغرفة، وجد من خلال نتائج XRD أن العينات كانت متعددة البلورات (كعبة، رباعي الزوايا، أحادي الميل، مكعب). أظهرت نتائج تحليل التبلور أن العينة (Al-Zn-(0%)Cu) ضمت (12.73%) من البلورات (ملتوية بنسبة (32.125%) و(0.4%)Cu) (العينة (Al-Zn-(0.4%)Cu) (العينة (Al-Zn-(1.2%)Cu) (العينة (Al-Zn-(2%)Cu) (العينة (Al-Zn-(2.2%)Cu) (العينة (Al-Zn-(1.2%)Cu) (العينة (Al-Zn-(2%)Cu) (العينة (Al-Zn-(2.2%)Cu) (العينة (Al-Zn-(2.2%)Cu) (العينة (Al-Zn-(2.2%)Cu) (العينة (Al-Zn-(2.2%)Cu). تم حساب الكثافة النظرية للأطوار الناتجة لكل عينة بوصفة معينة، مع الأخذ في الاعتبار بعض العوامل مثل التغيرات في الكثافة الذرية، وعدد نواز العناصر المكونة، وحجم خلية الوحدة.
1. Introduction

Composites are materials that are made up of two or more different materials, each of which has its own unique set of physical and chemical properties. These composites are often preferred over their individual constituents for a variety of reasons. Recent years have seen a rise in the study of Robotic Materials, composites with built-in capabilities for sensing, actuation, computation, and communication [1]. Aluminum-based alloys have been widely utilized in machinery since the seventeenth century due to their favorable structural, physical, mechanical, and tribological properties, as well as their cost-effective production methods. The specific qualities of an alloy are determined by the chemical composition, which refers to the proportion of alloying components to constituent elements [2]. Alloys composed of aluminum (Al) and zinc (Zn) are extensively employed in several commercial sectors, with notable prevalence in the aerospace and automobile domains. Bronze, brass, and cast iron are among the heavy metals that are commonly utilized in the composition of high-strength alloys. The extensive application of these materials is facilitated by their benefits, including durability, corrosion resistance, and malleability. Alloys possessing the following attributes, namely low density, high strength, high corrosion resistance, multi-phase microstructures, ease of fabrication and forming, low melting point, and ductility, have garnered significant attention. The structural basis is sufficiently grounded [3]. Industrial application of aluminum metal matrix composites has increased in recent decades. Metal, fiber, and ceramic like (Al2O3, SiC, B2C, TiC, TiB2 and graphite) increase aluminum alloy mechanical and tribological qualities [4]. Numerous studies have been undertaken to explore the reinforcing of aluminum using different processing techniques, such as utilizing powder-technology, the structural properties of metal matrix composites comprised of AlSi12 aluminum alloy reinforced with mullite porous preforms were investigated [5]. Garg P. et al. studied the effect of sintering temperature on the structural and mechanical characteristics of aluminum samples prepared by powder technology and reinforced with graphene powder [6]. G. Anil Kumar et al. conducted an investigation of the structural and mechanical characteristics of Al2O3 samples that were fabricated using powder technology. These samples were reinforced with B4C powder and Afterwards compared to samples reinforced with equivalent quantities of Al2O3 and SiC powder [7]. S. Khnsaa investigated the structural, physical, and mechanical properties of powder-processed metallic matrix compounds (Al/SiC and Al/B2C) [8]. A study used powder metallurgy to incorporate SiC-graphite and GNSs into aluminum matrix composites. Examined composite microstructure and reinforcement dispersion. Ball milling with thin GNSs deformed aluminum particles and introduced flaws into carbonaceous phases. The composite had less grain than graphite because GNSs were evenly distributed [9]. Using powder technology, Alam M. and Motgi B. analyzed the structural and mechanical properties of aluminum samples reinforced with differing proportions of SiC powder and fly ash [10]. This study aimed to explore the structural features of copper-reinforced Al-Zn composites, which had not been previously examined, due to the wide range of applications in which aluminum composites are employed.

2. Experimentally

2.1. Preparation Method

The composite material’s base ingredient was aluminum powder mixed with (10% Zn) powder, while the reinforcing material was Cu powder in different percentages. The research powders’ details are listed in Table 1.

![Table 1. Properties of the composite materials](https://doi.org/10.25130/tjps.v29i2.1493)

<table>
<thead>
<tr>
<th>Material</th>
<th>Purity %</th>
<th>Grain size µm</th>
<th>Density gm/cm³</th>
<th>Melting point C⁰</th>
<th>Manufacture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>99.98</td>
<td>&lt;50</td>
<td>2.70</td>
<td>660.0</td>
<td>china</td>
</tr>
<tr>
<td>Zn</td>
<td>99.99</td>
<td>&lt;50</td>
<td>7.14</td>
<td>419.5</td>
<td>china</td>
</tr>
<tr>
<td>Cu</td>
<td>99.99</td>
<td>&lt;50</td>
<td>8.94</td>
<td>1085</td>
<td>china</td>
</tr>
</tbody>
</table>

After determining the grain sizes using special sieves, we employed a sensitive electrical balance with an accuracy of (0.0001 gm) to weigh the powders before combining them into the compounds. Table 2 shows the weight ratios used in the study.

![Table 2: The weight ratios used in the study](https://doi.org/10.25130/tjps.v29i2.1493)

<table>
<thead>
<tr>
<th>Composites</th>
<th>Al</th>
<th>Zn</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>90.0%</td>
<td>10%</td>
<td>----</td>
</tr>
<tr>
<td>M2</td>
<td>89.6%</td>
<td>10%</td>
<td>0.4%</td>
</tr>
<tr>
<td>M3</td>
<td>88.8%</td>
<td>10%</td>
<td>1.2%</td>
</tr>
<tr>
<td>M4</td>
<td>88.0%</td>
<td>10%</td>
<td>2.0%</td>
</tr>
</tbody>
</table>

For (30 minutes), powders were manually combined with concentrated ethanol alcohol (as assistant factor) before being dried in an electric drying furnace at (50 °C) for (30 minutes) to remove moisture. The samples were shaped using the one-way pressing technique in a hardened carbon steel mold to produce cylinders with a diameter of (1.4 cm) once the mixing process was completed and a homogenous powder was obtained.

The mixed mixture was inserted in the pressing mold and pressed for (45 seconds) at (5 Ton) to avoid elastic return. Pressing machines were used. The
models were placed on ceramic pieces and gradually heated to the sintering temperature of (540 °C) in an electric oven for two hours, until the particles bonded together, porosity decreased, and mechanical resistance increased. The forms were allowed to slow cool inside the furnace until they reached room temperature.

3. Results and Discussion

3.1. XRD analysis

XRD analysis of the samples was performed using a (Philips PANanalytical X’Pert XRD System) The source consisted of (CuKα) radiation (λ =1.54 Å). Each sample was scanned with a step size of (0.1) in the 2θ range of (10 - 80), figures (1&2) illustrates the XRD pattern of (Al-Zn) composites with different proportions (0%, 0.4%, 1.2%, 2%)Cu. It was noticed that the formation of the polycrystalline phase was consistent with the powder diffraction file of JCPDS Card as shown in tables 3-6.

The observed peaks can be ascribed to the mean interparticle spacing inside the crystalline domains of the generated phases [11]. The greatest diffraction peak indicates crystalline material, while the lowest trough between the two peaks indicates amorphous material. The calculation of crystallinity (X_c) was determined based on the relative percentages [12]:

\[ X_c = \frac{A_c}{(A_c+ A_a)} \times 100\% \quad ...(1) \]

Where:

- \( A_c \): The area of crystalline peaks.
- \( A_a \): The area of amorphous peaks.

The degrees of crystallinity of samples (Al-Zn-(0%)Cu), (Al-Zn-(0.4%)Cu), (Al-Zn-(1.2%)Cu), and (Al-Zn-(2%)Cu) were (12.730, 32.125, 42.771, and 50.179)%, respectively.

The degree of crystallinity of the samples being examined is observed to increase with the higher percentage of added copper. Consequently, this increase in crystallinity results in an elevation of the X-ray reflection from the crystal planes, as evidenced by the heightened Bragg peaks according to the Scherrer formula [13,14,15]:

\[ D_{hkl} = \frac{K \lambda}{\beta_{hkl} \cos \theta} \quad ...(2) \]

Where \( \beta_{hkl} \) is the half width of \( hkl \) reflection, \( K \) is particle shape factor.
The volume V of the unit cell for the crystal phases was calculated [13,18,19,20]:

\[ V = a^3 \quad \ldots \ldots \quad (7) \]

Hexagonal:

\[ V = \frac{\sqrt{3}}{2} a^2 c \quad \ldots \ldots \quad (8) \]

Monoclinic:

\[ V = abc \sin \alpha \quad \ldots \ldots \quad (9) \]

Tetragonal:

\[ V = a^2 c \quad \ldots \ldots \quad (10) \]

The theoretical density \( \rho_{x-ray} \) of samples under study was calculated using equation (11) and discovered that the molar mass, which is dependent on the atomic mass and number of elements in the single phase and the unit cell size, changes for each phase [13,16,17]:

\[ \rho_{x-ray} = \frac{Z M_W}{N_A V} \quad \ldots \ldots \quad (11) \]

Where:

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
Chemical formula & Crystalline system & 20 degree & d_{measured} (\AA) & d_{standard} (\AA) & Rel. Intensities \\
\hline
Zn₆₆Al₆₂O₁₆ & Cubic/Fd-3m/227 & 36.2699 & 2.47686 & 2.40305 & 2.53 \\
Zn₆₆Al₆₂O₁₆ & Cubic/Fd-3m/227 & 38.6299 & 2.33080 & 2.34033 & 100 \\
Al₁₀₆₄O₁₄ & Tetragonal/I41/amd/141 & 44.9376 & 2.01721 & 1.99828 & 42.40 \\
Al₁₄₂O₁₂Zn₂₄ & Cubic/Fd-3m/227 & 65.2444 & 1.42055 & 1.41421 & 27.10 \\
O₂Zn₄ & Cubic/F-43m/216 & 70.2306 & 1.34024 & 1.33628 & 4.23 \\
Zn₆₆Al₆₂O₁₆ & Cubic/Fd-3m/227 & 78.3696 & 1.21917 & 1.21160 & 26.99 \\
\hline
\end{tabular}
\caption{XRD test results for (Al-Zn-(0\%))Cu composite}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
Chemical formula & Crystalline system & 20 degree & d_{measured} (\AA) & d_{standard} (\AA) & Rel. Intensities \\
\hline
Al₁₂₂Zn₁₂₂Cu₉₆ & Hexagonal/R3/146 & 35.894 & 2.50193 & 2.52322 & 1.96 \\
Cu₂O₂ & Hexagonal/C12/C1/15 & 38.6354 & 2.33048 & 2.31177 & 100 \\
Al₁₂₂Zn₁₂₂Cu₉₆ & Hexagonal/R3/146 & 44.9543 & 2.01650 & 2.04793 & 56.33 \\
Cu₂Al₂O₄ & Hexagonal/P63/mmc/194 & 65.4389 & 1.42627 & 1.42900 & 31.61 \\
Cu₁₀₆Zn₁₆ & Hexagonal/P63/mmc/194 & 78.5513 & 1.21680 & 1.22586 & 27.88 \\
\hline
\end{tabular}
\caption{XRD test results for (Al-Zn-(0.4\%))Cu composite}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
Chemical formula & Crystalline system & 20 degree & d_{measured} (\AA) & d_{standard} (\AA) & Rel. Intensities \\
\hline
Cu₂O₂ & Monoclinic/C12/C1/15 & 38.6520 & 2.32952 & 2.33946 & 100 \\
Al₁₂₂Zn₁₂₂Cu₉₆ & Hexagonal/R3/146 & 43.4118 & 2.08450 & 2.08633 & 5.39 \\
Cu₂Al₂O₄ & Cubic/Fd-3m/227 & 44.8362 & 2.02145 & 2.02150 & 45.32 \\
Cu₂Al₂O₄ & Hexagonal/P63/mmc/194 & 54.5450 & 1.68245 & 1.66837 & 0.92 \\
Cu₁₀₆Zn₁₆ & Cubic/Fd-3m/227 & 65.2896 & 1.42917 & 1.42853 & 27.01 \\
Al₁₂₂Zn₁₂₂Cu₉₆ & Cubic/Fd-3m/227 & 78.4328 & 1.21834 & 1.21999 & 25.95 \\
\hline
\end{tabular}
\caption{XRD test results for (Al-Zn-(1.2\%))Cu composite}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
Chemical formula & Crystalline system & 20 degree & d_{measured} (\AA) & d_{standard} (\AA) & Rel. Intensities \\
\hline
Al₁₀₆O₄Cu₃ & Hexagonal/R-3m/166 & 36.5370 & 2.45936 & 2.45316 & 4.89 \\
Zn₆₆Al₆₂O₁₆ & Cubic/Fd-3m/227 & 38.3740 & 2.34576 & 2.34897 & 100.00 \\
Cu₁₀₆Zn₁₆ & Hexagonal/P63/mmc/194 & 42.9327 & 2.10665 & 2.07805 & 47.95 \\
Cu₁₀₆Zn₁₆ & Cubic/Fd-3m/227 & 44.7191 & 2.02655 & 2.02150 & 45.55 \\
Al₁₂₂Zn₁₂₂Cu₉₆ & Hexagonal/R3/146 & 65.0176 & 1.43449 & 1.43250 & 29.07 \\
Zn₆₆Al₆₂O₁₆ & Cubic/Fd-3m/227 & 70.0322 & 1.34355 & 1.34295 & 10.81 \\
Al₁₂₂Zn₁₂₂Cu₉₆ & Hexagonal/R3/146 & 70.5472 & 1.33500 & 1.33795 & 24.72 \\
Cu₁₀₆Zn₁₆ & Cubic/Fd-3m/227 & 78.1294 & 1.22231 & 1.21780 & 31.91 \\
\hline
\end{tabular}
\caption{XRD test results for M4: (Al-Zn-(2\%))Cu composite}
\end{table}
In figure (3), we see a VESTA drawing depicting the crystal structure of the phases formed in samples under study.
Fig. 3: The crystal structure of the phases generated in the samples under study

3.2. EDS analysis
EDS characterization was carried out using a (FESEM system equipped by Oxford instrument in Iran). In order to confirm the (Al-Zn) composites, an EDS analysis was performed. EDS measurements were focused on a different area and corresponding peaks are shown in the Figures 4-7 and Tables 11-14.

Fig. 4: EDS test plot and FESEM image of (Al-Zn-(%0)Cu) composites

Fig. 5: EDS test plot and FESEM image of (Al-Zn-(%0.4)Cu) composites
4. Conclusions

Aluminum compounds are essential in many fields due to their characteristics. Some of them were made and studied in this study. The XRD analysis of the powder metallurgy-prepared samples under study revealed the following about their structural properties: Crystal systems observed in samples under study include (cubic, tetragonal, monoclinic, and hexagonal), indicating that the material is polycrystalline. The results of the crystallinity...
analysis showed that sample (Al-Zn-(0)%Cu) was (12.730%) crystallized, sample (Al-Zn-(0.4)%Cu) was (32.125%) crystallized, sample (Al-Zn-(1.2)%Cu) was (42.771%) crystallized, and sample (Al-Zn-(2)%Cu) was (50.179%) crystallized. Theoretical density of the phases was determined for each sample using independent calculations, taking into consideration factors such as variations in atomic mass, the number of atoms of the constituent elements, and the size of the unit cell. The studied samples can be utilized to make cars, planes, coatings, and radiation shields.

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[16] Jasem İ. K., Abdul-Aziz A.F., Ibrahim N.M., 2018, Fabrication and study of the structural and spectral properties of the composites (y) Mn0.6 Zn0.4 Fe2O4 + (1-y) PZT prepared by the powder technology method, Tikrit Journal of Pure Science, 23 (10).