# Experimental assessment of the icosahedral phase of Al-Cu-Fe quasicrystalline alloy for enhanced solar absorption

**Abdul Hai Alami[1], Afra Alketbi[2], Meera Almheiri[2] and Jehad Abed[2]**
1. Assistant Professor, Sustainable and Renewable Energy Engineering Department,
2. Research Assistant, Sustainable and Renewable Energy Engineering Department,
University of Sharjah, 27272, Sharjah, United Arab Emirates
Corresponding author: aalalami@sharjah.ac.ae



**Abstract**

This paper investigates the synthesis, microstructural characterization and thermal and optical properties of Al-Cu-Fe quasicrystalline system for selective solar absorption applications. A nominal composition of $Al_{64}Cu_{25}Fe_{11}$ was produced by mechanical alloying (MA) using high-energy ball milling. Subsequent annealing was performed on the quasicrystalline samples at temperature of 200 °C for 20 hours. This was done along with monitoring the samples crystallographic morphology via X-ray diffraction (XRD) through out the milling process and the subsequent annealing. The resulting alloys were examined by scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) to verify how efficient the inter-diffusion of the elements. Through the optical spectroscopy results, it is clear that the absorption performance of Al-Cu-Fe sample is better than $TiO_2$ in the whole range of spectrum of the optical test graph (300 nm to 1000 nm) regardless of the milling time and the annealing period. Also, Differential Scanning Calorimetry (DSC) was used to indicate the thermal stability of the formed solid solution as well as in the demonstration of the existing phases when correlated with the XRD graphs. High-energy ball milling has proven to be an effective method for producing homogeneous phases of quasicrystalline materials, with enhanced solar absorption properties.

**Keywords:** Quasicrystalline alloys; Al-Cu-Fe systems; selective solar absorbers; mechanical alloying

## 1. Introduction

In the past few years, the Al–Cu–Fe system with the developed icosahedral (I) quasicrystalline (QC) phase has been the focus of many studies. The components of the system are considered to be cheap, easily available and technologically promising compared to those of other systems [1]. The icosahedral quasicrystalline Al–Cu–Fe system has a 5-fold symmetry in its structure. It can be either produced to be stable or metastable depending on the methods used in the production process [2]. The formation of quasicrystalline phases can be accomplished through various process which include solidification of molten alloys, rapid quenching techniques by either by melt spinning or gas atomization, electrodeposition, gas evaporation and mechanical alloying [3]. Mechanical alloying is used here to produce an alloy that possesses desirable mechanical and thermal, microstructural properties, and most importantly, optical properties for enhanced solar absorptivity [4, 5]. Mechanical alloying (MA) is commonly known for its ability to produce metastable alloys, but some studies shows that it is also capable of forming the i-phase in the Al-Cu-Fe ternary system [6]. Previous studies presented some optimal combination of ball milling and annealing was found to form the single-phase QC alloys [7, 8]. In this techniques pure constituents are ball milled together to form solid solutions with exact compositions under the forces of the collision, that causes continuous fracturing and cold welding [9]. There are many factors affecting this process, namely, milling time, milling temperature, post milling thermal processing, and alloy composition [10]. The formation of icosahedral phase (i-phase) by the method mechanical alloying can offer an insight into the development of the microstructure of the material and phase transformations that occurred during the milling.

This work investigates the feasibility of the synthesis of Al-Cu-Fe quasicrystalline alloy that would be suitable for enhancing solar absorption in the UV-Vis range. The synthesis of the alloys system is done through high-energy ball milling, which is a mechanical alloying technique, and the resulting microstructure and thermal and optical properties will be analyzed and measured as milling time is increased and attention is given to the phase transformations that occur during heating.

## 2. Experimental

### 2.1. Synthesis

An elemental blend of high purity aluminium (≥ 93 %, fine), copper (< 425 μm, 99.5 %) and iron (≥ 99 %, fine) powders corresponding to the nominal compositions of $Al_{64}Cu_{25}Fe_{11}$ has been mechanically alloyed. The grinding bowl initially held a sample of 10 g with six 10 mm zirconia as the milling media. A 450 rpm milling speed and (2:1) ball to powder weight ratio was maintained through the milling. Milling is paused after each hour to cool the equipment and a sample is taken every 4 hours for further heat treatment and characterization. Subsequent annealing was performed on the quasicrystalline samples at temperature of 200 °C for 20 hours to further develop the microstructure. The milling is terminated once the required microstructure is obtained.

### 2.2. Microstructural analysis via SEM and XRD

The powder X-ray diffraction (XRD) patterns, plotted for five powder samples collected at a two-hour interval for eight hours, provide an insight into extent and progress of crystallization and the composition and grain structure of the developing

## 4. Conclusion

In this paper mechanical alloying (MA) was proposed as simple method of synthesis with significant technical advantages; economical, environmental friendly and uses minimum amount of energy comparing to other materials synthesizing methods. High-energy ball milling was utilized in this work to produce solar absorber material with a composition of $Al_{64}Cu_{25}Fe_{11}$ targeting a icosahedral quasicrystalline alloy. Thus, a detailed analysis is carried out in a small increments of time while milling and a sample is to be taken for SEM-EDS, XRD, thermal and optical analysis.

The system was produced by mechanically alloying 64 %wt of Al, 25 %wt of Cu and 11 %wt of Fe, for 56 hours of milling then annealed at temperature of 200 °C for 20 hours. SEM graphs showed the development of particles size with milling time, and the agglomeration of the powder. Where as the XRD graphs were utilized in identifying the new phases developed during the alloying process. It was seen that an iQC phase was produces after 52 h of milling and 20 hours of subsequent annealing. DSC analysis was used in correlation with the XRD graphs to prove the phases that were formed. It is clear that the absorption performance of Al-Cu-Fe is better than $TiO_2$ in the whole range of spectrum of the optical test graph (300 nm to 1000 nm).

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