# Peak profile analysis of Al-Cu alloy prepared by Tubular Metal Additive Extrusion (TMAE) technique

*Senthil Saravanan M S[1], Mohammad Israr[2]*
[1] Department of Mechanical Engineering,
Sree Buddha College of Engineering, Pattoor, Alappuzha, Kerala-690529
[2] President, Maryam Abacha American University of Nigeria
Email ID : bhatranitt@gmail.com

**Abstract:** The development of lightweight metal matrix composites with enhanced structural and functional properties is important in advanced manufacturing. This study investigates a tubular metal additive extrusion (TMAE) technique for fabricating aluminium-based composites containing copper and carbon nanotubes (CNTs). The process involves powder processing, compaction, and hot extrusion to produce tubular metallic structures. Aluminium, copper powder, and CNTs were used as constituent materials, and hot extrusion was performed at 550 °C under an applied pressure of approximately 8 MPa. The fabricated samples were characterized using X-ray diffraction (XRD), optical microscopy, and scanning electron microscopy, with emphasis on changes in diffraction peak profiles.

The XRD results revealed significant modifications in the aluminium diffraction pattern following copper addition. The principal aluminium peak shifted from approximately 38.2° to 38.4°, while additional peaks corresponding to $Al_2Cu$ indicated intermetallic phase formation. With CNT incorporation, traces of the characteristic carbon-related diffraction feature were observed, along with changes in aluminium peak intensity and position. The Al-Cu-CNT sample exhibited a smaller peak shift of approximately 0.02° compared with the Al-Cu sample. Peak broadening was also observed, indicating changes in crystallographic structure and grain characteristics. The findings demonstrate the potential of TMAE for producing aluminium-based tubular composite materials.

**Keywords**: Aluminium matrix composite Al-Cu alloy; Carbon nanotubes, Tubular metal additive extrusion, Hot extrusion, X-ray diffraction, Peak profile analysis

## Introduction

Additive manufacturing (AM) has developed rapidly as an alternative to conventional manufacturing because of its ability to produce components by adding material in a controlled manner. Unlike conventional subtractive processes, where material is removed from a bulk material, additive manufacturing offers greater flexibility in producing complex geometries and can reduce material wastage. These advantages have encouraged the use of metal additive manufacturing in several demanding fields, including aerospace, automotive, energy, and biomedical applications [1,2].

Among the materials used in advanced manufacturing, aluminium and its alloys are particularly attractive because of their low density, good corrosion resistance, and favourable specific mechanical properties. These characteristics make aluminium-based materials suitable for lightweight structural applications. However, the performance of conventional aluminium can be further improved by introducing suitable alloying elements and reinforcing materials. Aluminium matrix composites (AMCs) have therefore received considerable attention because their properties can be tailored by controlling the type, size, and distribution of the reinforcement [2,3].

Copper is one of the important alloying elements used with aluminium and can significantly influence the microstructure and mechanical behaviour of aluminium-based materials. During thermal processing, aluminium and copper can also interact to form intermetallic phases such as $Al_2Cu$, which may contribute to changes in the resulting material structure and properties [3,4]. In parallel, carbon nanotubes (CNTs) have attracted considerable interest as nanoscale reinforcements because of their exceptional mechanical properties and potential to improve the strength and structural stability of aluminium matrices. Previous studies have demonstrated the feasibility of producing CNT-reinforced aluminium composites using powder extrusion and hot extrusion routes [5,6].

Hot extrusion is particularly useful for processing aluminium-based composites because the combined effects of temperature, pressure, and plastic deformation can promote consolidation of powder particles and influence the evolution of the microstructure. Studies on hot-extruded aluminium composites have shown that extrusion can modify grain structure and consequently affect the mechanical performance of the material [6,7].

In this context, the present study explores a Tubular Metal Additive Extrusion (TMAE) technique for producing cylindrical and tubular aluminium-based structures. The proposed approach combines powder processing, compaction, and hot extrusion to develop tubular components while allowing additional constituents such as copper and CNTs to be incorporated into the aluminium matrix. The approach provides an opportunity to investigate the interaction between alloying elements, nanoscale reinforcement, and extrusion-induced structural changes.

The primary focus of the present investigation is the X-ray diffraction (XRD) peak-profile behaviour of aluminium, Al-Cu, and Al-Cu-CNT materials fabricated using the proposed process. Particular attention is given to changes in diffraction peak position, peak broadening, and phase formation. Understanding these changes is important for establishing the relationship between material composition, processing conditions, and crystallographic structure. The study therefore aims to provide an initial understanding of the structural modifications produced by copper and CNT incorporation during tubular metal additive extrusion.

## Materials and Experimental Method

### **Material**s

The materials employed in the investigation consisted of:

- Aluminium rods
- Aluminium powder
- Copper powder
- Carbon nanotubes

The aluminium matrix was modified through the incorporation of copper and CNT constituents

## Tubular Metal Additive Extrusion

The fabrication process was based on a hot extrusion route. The principal processing stages consisted of raw-material preparation, powder processing, cold compaction, hot extrusion and subsequent characterization.

The process sequence presented in the study can be summarized as:

Raw materials → Powder processing → Cold compaction → Hot extrusion → Characterization → Microstructural and mechanical analysis

The characterization stage included optical microscopy, XRD and scanning electron microscopy. Microhardness and tensile testing were also identified as mechanical characterization methods.

### Processing Parameters

Hot extrusion was performed at approximately 550 °C. The reported loading pressure was 80 $kg/cm^2$, corresponding approximately to 8 MPa.
The fabrication procedure involved powder selection, mixing and filling, compaction, hot extrusion and post-processing. The uploaded presentation also documents the hot-extrusion apparatus, controller and fabricated extruded sample.

## Results and Discussion

### XRD Analysis of Pure Aluminium

The XRD profile of the pure aluminium sample shown in Figure 1 exhibited the characteristic aluminium diffraction peaks. The uploaded results indicate that no additional peaks associated with other constituents or intermetallic phases were identified in the pure aluminium sample. This provides a reference diffraction profile against which the Al-Cu and Al-Cu-CNT materials can be compared.

The presence of well-defined aluminium peaks establishes the initial crystallographic condition of the matrix before the introduction of copper and CNT reinforcement

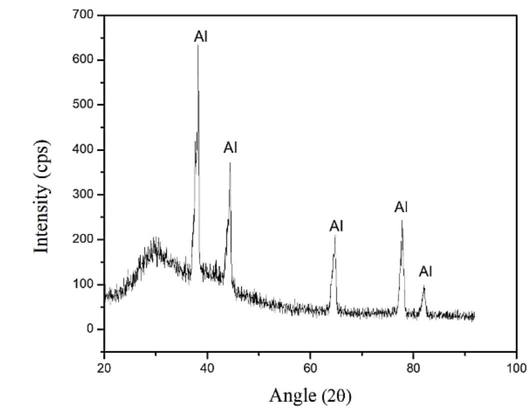


*Figure 1. XRD profile of pure Aluminum*

**XRD Analysis of Al-Cu**

The incorporation of copper produced significant changes in the XRD profile which is shown in Figure 2. A close examination of the diffraction region around 44° showed closely positioned aluminium and copper-related peaks. The reported copper peak occurs at approximately 44.8°, while the aluminium-related peak occurs close to 45. Additional peaks attributed to $Al_2Cu$ were identified around approximately 50°, with further $Al_2Cu$-related peaks reported near approximately 78° and 82°.

These observations indicate that the thermal and mechanical conditions associated with the extrusion process were sufficient to promote interaction between aluminium and copper. The formation of $Al_2Cu$ is particularly significant because intermetallic formation can strongly influence the microstructure and subsequent mechanical behaviour of aluminium-copper systems.

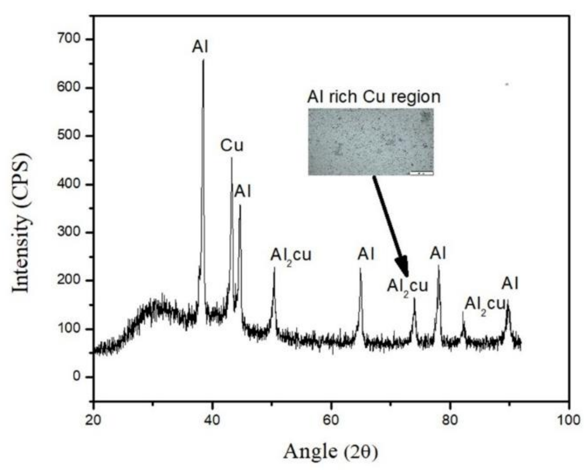


*Figure 2. XRD profile of Al-Cu*

Thus, the XRD analysis demonstrates that the addition of copper does not simply result in a physical mixture of aluminium and copper. Instead, the processing conditions promote chemical interaction and phase formation within the aluminium matrix.

### XRD Analysis of Al-Cu-CNT

The addition of CNTs resulted in further changes in the diffraction profile which is shown in Figure 3
The characteristic carbon-related diffraction feature of CNTs is expected near approximately 26.3°. The experimental profile showed traces attributed to CNTs along with modifications in the XRD pattern. The study also reports that the presence of CNTs reduced the extent of reaction between aluminium and copper compared with the Al-Cu condition.
The observed behaviour can be associated with the reinforcing effect of CNTs within the aluminium matrix. The uploaded study interprets the CNTs as a strengthening constituent capable of influencing aluminium grain behaviour and reducing the extent of interaction between the matrix and copper.
However, the relatively weak CNT-related diffraction response also indicates that the amount and/or dispersion of CNTs can influence their detectability through XRD. Consequently, complementary characterization such as SEM and microscopic analysis is important for establishing the distribution of CNTs.

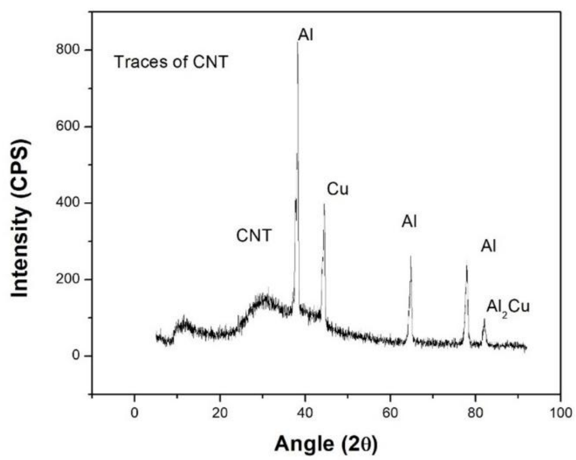


*Figure 3. XRD profile of Al-Cu-CNT*

### Comparative XRD Profile

The stacked XRD patterns of aluminium, Al-Cu and Al-Cu-CNT demonstrate the progressive modification of the aluminium diffraction profile following the addition of copper and CNTs. The comparison shows that the constituent additions influence both peak position and peak profile.
The comparative analysis demonstrates three important observations from Figure 4

- ❖ Aluminium provides the baseline diffraction profile.
- ❖ Copper addition introduces additional phase-related peaks and modifies the aluminium peak position.
- ❖ CNT addition produces further modifications to the diffraction profile while reducing the extent of aluminium-copper reaction reported for the Al-Cu condition.

These observations demonstrate that XRD peak-profile analysis can be used as an effective tool for monitoring structural changes during the development of aluminium-based composites.

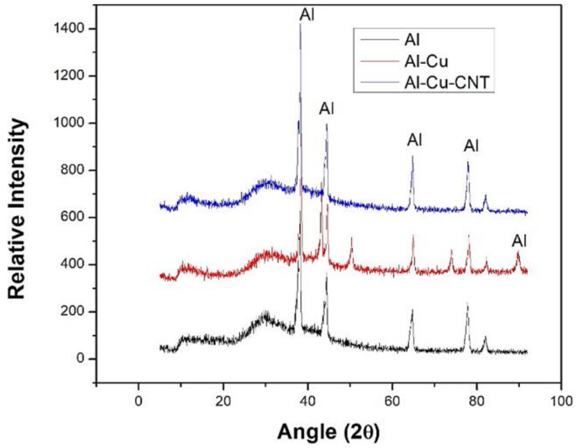


*Figure 4. Stacked XRD profile of samples*

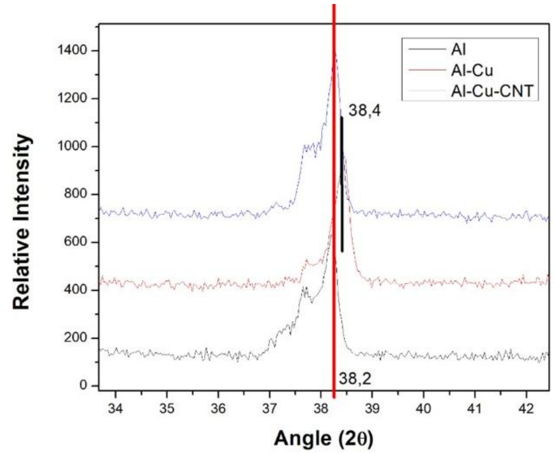


*Figure 5. XRD profile peak shift of samples*

One of the most significant findings of the investigation is the change in the principal aluminium peak position shown in Figure 5. The principal aluminium peak was initially reported at approximately 38.2°. Following copper addition, the peak shifted to approximately 38.4°. This represents a shift towards a higher diffraction angle.

A shift towards a higher diffraction angle corresponds to a reduction in the associated inter-planar spacing when the X-ray wavelength remains constant. The observed change from approximately 38.2° to 38.4° therefore indicates that copper incorporation modified the crystallographic environment of the aluminium matrix. The addition of CNTs resulted in a much smaller additional change. The study reports an approximately 0.02° change associated with CNT addition to the Al-Cu system.

This suggests that the structural influence of copper on the aluminium diffraction peak is more pronounced than the additional peak-position change associated with CNT incorporation under the investigated processing conditions

**Conclusion**

The present investigation successfully demonstrated the feasibility of a tubular metal additive extrusion (TMAE) approach for fabricating aluminium-based materials through powder processing and hot extrusion. The extrusion process was carried out at approximately 550 °C under a loading pressure of about 8 MPa. X-ray diffraction analysis of the pure aluminium sample showed the characteristic diffraction peaks without significant additional phase-related peaks. The incorporation of copper produced noticeable changes in the aluminium diffraction profile, together with additional peaks attributed to the formation of $Al_2Cu$. In particular, the principal aluminium peak shifted from approximately 38.2° to 38.4°, indicating a change in the crystallographic environment and interplanar spacing of the aluminium matrix. Further modification of the diffraction profile was observed after CNT incorporation, including traces of the carbon-related diffraction feature and an additional peak-position change of approximately 0.02°. Peak broadening was also observed, suggesting changes in the crystallite and grain structure during extrusion. The results indicate that copper contributes to structural refinement, while CNT incorporation can contribute to strengthening and restricting grain growth. Overall, the findings demonstrate the potential of the TMAE technique for developing aluminium-based composite tubular structures and provide a basis for further investigation of their microstructural and mechanical properties.

**References**

1. Kose, S. (2024). Investigation of the mechanical and tribological properties of aluminum powder filled with cyclo-olefin-copolymer composites, *Journal of Radiation Research and Applied Sciences*.

2. Wu, X., & Zhang, W. (2024). A review on aluminium matrix composites characteristics and applications for automotive sector, *Heliyon*. https://doi.org/10.1016/j.heliyon.2024.e38576

3. Wang, C., Ma, L., Ma, X., Wang, T., Jiang, Z., Hasan, M., & Zhao, J. (2023). Effect of annealing temperature on microstructure and tensile properties of copper/aluminium composite thin strip, *The Nonferrous Metals Society of China*.

4. Thewes, A., Reinders, P. M., Paschke, H., Bruckner, T., Templin, D., Lechner, S., Müller, S., Paulus, M., & Sternemann, C. (2024). Surface modifications to reduce wear in hot extrusion of copper, *Wear*.

5. Xavior, M. A., Ranganathan, N., Prashantha Kumar, H. G., Joel, J., & Ashwath, P. (2018). Mechanical properties evaluation of hot extruded AA 2024–Graphene nanocomposites, *Materials Today: Proceedings*.

6. Bharath, K., Mandal, A., Karmakar, A., Khanra, A. K., & Davidson, M. J. (2020). Understanding the effect of hot extrusion on the evolution of microstructure and associated mechanical properties in sintered Al-Cu-Mg alloys, *Materials Characterization*.

7. Mehdipour, F., Delrieux, T., Maurer, F., Grunwaldt, J.-D., Klahn, C., & Dittmeyer, R. (2024). Opportunities and limitations of metal additive manufacturing of structured catalytic converters, *Catalysis Communications*.

8. Pak, J.-H., Kim, G.-N., Hwang, S.-G., Kim, B.-S., Noh, J.-P., & Huh, S.-C. (2016). Mechanical properties of Cu matrix composite fabricated by extrusion process, *The Nonferrous Metals Society of China*.

9. Miller, W. S., Zhuang, L., Bottema, J., Wittebrood, A. J., De Smet, P., Haszler, A., & Vieregge, A. (2000). Recent development in aluminium alloys for the automotive industry, *Materials Science and Engineering*.

10. Prashantha Kumar, H. G., Anthony Xavior, M., Ashwath, P., Joel, J., Shivprasad Hosmani, S., Shivalli, P. M., & Chakraborty, K. (2017). Synthesis and property evaluation of hot extruded AA2024-MWCNT nanocomposites, *Materials Today: Proceedings*.