Effect of Microwave Heat Treatment on Mechanical Properties of AA6061 Sheet Metal

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Abstract

Recently aluminum alloy sheet, exclusively AA 6061 T4 is used in the automotive, aircraft, marine and construction industries due to its excellent properties such as noncorrosive, strength to weight ratio and rewards over than steel in ductility. Heat treatment process is agreed more for refinement of grain structures which liberate the residual stress generated from forming and elevate the tensile, yield strength of the material. Mostly heat treatment processes carried over by conventional furnace where heat transfer mode was convection and radiation. In conventional heat treatment process, heat transferring from material surface layer to inner core is through conduction mode. This yields a non-uniform temperature in the thickness direction. To meet agile manufacturing requirements, microwave heat treatment is an inevitable, realistic and economic method over than the conventional heat treating method. This process requires a microwave furnace and a simple masking arrangement. This study aims to eliminate the pitfall by focusing on microwave heat treatment rather than conventional methods, to obtain uniform temperature distribution throughout the material, maximize the physical and mechanical properties and to minimize the power consumption. Also a comparison of the physical and mechanical properties with conventionally heat treated is carried out.

Keywords: AA6061, Microwave, Tensile test, Micro-hardness, Microstructure.

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1. Introduction

Aluminium alloy has normal strength with low density and very good corrosive resistance. In engineering applications, it is needed to improve strength and hardness of the material. It necessitates a heat treatment process for improving mechanical properties. Microwave energy has been used for fast four to five decades in a variety of applications like food processing and medical therapy. At present, microwave energy has emerged, as one of the superior and the greatest material processing techniques. Microwave post heat treatment of mechanical processed components is a newer technique which is employed in this study. Earlier period microwave was used efficiently to process ceramic materials. In microwave processing, microwave energy heats the material at the molecular level [1], which leads to uniform bulk heating, conversely in the conventional heating systems, material heated from the surface to inner core which produces thermal stress and longer time required for homogenization [2,3,4]. Microwave annealing of cartridge brass was reported. The hardness and fracture strength of microwave treated components were reported to be higher than conventionally heat treated ones [5,6]. Microwave heat treating processes can be used for a wide variety of surface treatments such as carburizing, carbonitriding, chromizing, and boronizing [7]. Microwave joining of stainless steel (SS-316) to mild steel (MS) in bulk form was successfully carried out using a multi-mode applicator at 2.45GHz and 900W [8]. Microwave heat treatment of the copper-graphite composite was studied [9] and hardness of the composite is improved due to pore closures. Based on the literature reports, the research on the microwave heat treatment of sheet metal is very limited. In this paper Al-6061 sheet is heat treated using multi-mode microwave applicator at 2.45GHz and 850W and its effect on mechanical properties is discussed in detail.

2. Material and Methodology

2.1. Material

The material used in this experiment is Aluminium 6061-T4 sheet metal with 1.15 mm thickness obtained with the cold rolled condition. The chemical composition was determined by chemical spectral analysis and reported in the table 1.

| Element | Mg | Si | Cu | Mn | Fe | Cr | Zn | Al      |
|---------|----|----|----|----|----|----|----|--------|
| Observed| 0.94 | 0.71 | 0.3 | 0.098 | 0.47 | 0.19 | 0.13 | Bal.   |
| Nominal | 0.8-1.2 | 0.4-0.8 | 0.15-0.4 | 0.15 max | 0.7 max | 0.04-0.35 | 0.25max | Bal.   |

2.2. Methodology and results

AA6061 sheets with thickness of 1.15 mm were used for tensile tests and microstructure observations. The tensile specimens prepared with 25 mm gauge length and 6 mm gauge width as per ASTM E-8 standard, as shown in figure 1 by EDM wire cutting machine.
2.3. Microwave heat treatment setup

The microwave furnace of 850 watts is used to conduct experiment. The set up and specimen arrangement within the furnace is shown in figure 2. The specimens are masked with alumina oxide layer as a heat insulator and then covered with graphite layer as susceptor. The samples were heat treated at 350°C at 10 min. Embedded temperature controller was used to control processing temperature. Microwave heat treatment is a rapid thermal processing to reach a high temperature at lowest time.

Fig 2 Microwave heat treatment setup

The samples were prepared in the size of 25 mm x 25 mm for hardness measurements. Hardness of specimens before and after heat treated was carried out using a Micro Vickers Hardness (HMV) instrument with 0.5 kg load. Four tests were performed per sample and they were averaged. The hardness obtained as-received and after heat treatment conditions as reported in table 2.

| Sl.No | Specimen Details          | Hardness Values (HV) | Average (HV) |
|-------|---------------------------|----------------------|--------------|
| 1     | Before Heat Treated       | 92.9, 93.5, 94.5, 93.8 | 94           |
|       | Conventional Heat Treated | 40.4, 44.1, 46.2, 40.1 | 40           |
| 2     | Microwave Heat Treated    | 76.9, 73.5, 74.5, 76.3 | 75           |

Tensile tests of the specimens were performed by using UTM capacity of 100-500 KN and feed rate of 0.01 mm/min at room temperature with strain rate 0.016 s⁻¹ has reported in the following tables 3 and 4.

| Heat treatment      | Orientation relative to rolling direction | Yield strength (MPa) | Tensile strength (MPa) | σ_y (MPa) | σ_u (MPa) | n   |
|---------------------|-------------------------------------------|----------------------|------------------------|-----------|-----------|-----|
| Before Heat Treated | 0°                                         | 216.10               | 312.15                 | 214       | 311       | 0.23|
|                     | 45°                                        | 209.35               | 310.15                 |           |           |     |
|                     | 90°                                        | 222.40               | 311.90                 |           |           |     |
| Microwave Heat Treated | 0°                                         | 188.08               | 221.80                 |           |           |     |
|                      | 45°                                        | 186.60               | 227.70                 | 188       | 226       | 0.31|
|                      | 90°                                        | 192.13               | 226.80                 |           |           |     |

Average = (X₀ + 2X₄5 + X₉₀)/4 where X is σ_y, σ_u, and n
Table 4 Heat Treatment Vs Mechanical Properties

| Heat treatment             | Orientation relative to rolling direction | Yield strength (MPa) | Tensile strength (MPa) | $\sigma_y$ (MPa) | $\sigma_u$ (MPa) | $n$  |
|---------------------------|-------------------------------------------|----------------------|------------------------|-----------------|-----------------|-----|
| Conventional Heat Treated | $0^\circ$                                  | 131.40               | 174.45                 | 136             | 181             | 0.26|
|                           | $45^\circ$                                 | 132.70               | 182.35                 |                 |                 |     |
|                           | $90^\circ$                                 | 147.20               | 185.70                 |                 |                 |     |
| Microwave Heat Treated    | $0^\circ$                                  | 188.08               | 221.80                 | 188             | 226             | 0.31|
|                           | $45^\circ$                                 | 186.60               | 227.70                 |                 |                 |     |
|                           | $90^\circ$                                 | 192.13               | 226.80                 |                 |                 |     |

Average = ($X_0 + 2X_{45} + X_{90}$)/4 where X is $\sigma_y$, $\sigma_u$, and $n$

Microstructure analysis: The specimen for microscopic inspection is cut by resin bonded SiC discs to prevent transform in microstructure, due to heat and mechanical damage. After mounting, grinding is carried out with enrichment of paper grades 240, 400, 600, 1000 (SiC grains per square inch). The samples were polished and etched with Keller’s Reagent for a time of 25 sec to reveal microstructure. The optical microscope attached with a 3M pixel camera and De-winter Material plus version-2 software is used to study and evaluate the microstructure.

3. Results and Discussion

From the tables 3 and 4 it is observed that the as-received condition specimen has 0.23 as strain hardening coefficient and it is increased by 13% and 35% due to conventional heat treatment and microwave heat treatment respectively. This indicates good flow stress and formability can be obtained in microwave heat treatment. It is also been observed, that yield stress and ultimate stress values are increasing from 136 MPa to 188 MPa and 181 MPa to 226 MPa by microwave heat treatment, indicating material strength have been enhanced by microwave heat treatment compared to conventional furnace heat treatment.

![Microstructure of Al 6061-T4](image1)

![Microstructure of heat treated specimen](image2)
The microstructures (Fig. 3 & Fig. 4) show fine grained matrix with the eutectic particles that are sparsely distributed precipitates in aluminum solid solution. Conversely, microwave heat treated samples, fine grained matrix with the eutectic particles that are more evenly distributed precipitates in aluminum solid solution. Microwave absorbing condition gives by the graphite layer; significantly modify heating characteristics of the metal sheet. The microstructure shows that the matrix is solution treated and precipitation hardened.

Hardness of material is enhanced from 40 HV to 75 HV indicates that heat treatment by microwave furnace yield better productivity, evident from the table 2. Due to volumetric heating of the microwave, the microstructure is refined. Figure 5(a)-(c) shows the Stress Vs Strain curves for before heat treated, Conventional and microwave furnace heat treated respectively. These results indicate microwave heat treated specimen yield high strain percentage in all orientations. Also in figure 5(d), tensile and yield stress increases from 136 MPa to 188 MPa and 181 MPa to 226 MPa respectively. Figure 6, shows that high strain hardening coefficient obtained by microwave heat treatment, indicates that microwave heat treated sample shows higher strain to failure.

![Stress Vs Strain](image)

(a) Stress Vs Strain % (Before Heat Treated)  
(b) Stress Vs Strain % (Conventional Method)

(c) Stress Vs Strain % (Microwave Furnace)  
(d) Conventional Vs Microwave furnace

Fig. 5 (a)-(d) Stress Vs Strain
4. Conclusions

Aluminium alloys 6061 has been heat treated by conventional and microwave furnace and the obtained results are summarized below.

1. Tensile and yield strength increases with shorter duration of heat treatment and less power consumption due to heat transfer in the form of heat conversion.
2. Increasing on strain hardening coefficient value to 35 percent indicates high productivity.
3. Heat treated specimen shows fine particles of eutectic precipitated. It indicates that heat treated sample has more hardness.
4. The major advantage of the microwave heat treatment method is that specimen is not bending while processing, but the bending of specimen is occurring in the case of conventional treatment.
5. In microwave heat treatment, heat transfer is uniform all over the surface due to volumetric heating.

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