The selection of reliable materials for fasteners fabrication is one of the most important problems in aircraft construction. One widely used alloy for fasteners and rivets is 2024 (V65) aluminum. It is a wrought alloy that is ductile enough to be deformed at room temperature after solution treatment and precipitation hardening. This was the main reason the alloy was used at aviation plants in the former Soviet Union.

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The thermomechanical heat treatment (TMHT) of semi-finished products made of wrought aluminum alloys consists of deformation immediately after solution treatment, with subsequent quenching and aging with standard regimes. This process increases the alloy’s ductility. Consequently, it became desirable to examine the possibility of applying TMHT to 2024 aluminum to manufacture rivets from it.

However, there were many obstacles to be overcome before this alloy could be applied as aircraft fasteners. Among these were its tendency toward grain growth at solution treatment, the presence of large inclusions of manganese intermetallic compounds, and its tendency to age at room temperature after final heat treatment. The alloy did not have enough ductility for the plastic deformation required of rivets during installation. Our results showed the presence of micro cracks on the head of rivets during installation, which result in considerable additional expenses during assembly. Each defective rivet had to be drilled out and another installed, resulting in reduced productivity poor quality joints.

The purpose of this article is to review our explorations on how the TMHT process can be applied to 2024 aluminum wire. We’ve assumed that the drawing the wire immediately after quenching could be an effective method of breaking insoluble intermetallic manganese compounds. This approach, along with the dispersal of enough recrystallized structures after final heat treatment, will essentially increase the ductility of 2024 wire.

This technique permits the manufacture of rivets without reducing their technological and strength characteristics and also increases their shelf life. This shelf life is the allowable time interval between heat treatment and rivet fabrication. It is the period during which rivets can be warehoused before the natural aging process and ductility reduction set in. By using the TMHT process rivets can stay on the shelves up to one year.

Storage Time and Properties
Our research was undertaken to determine how mechanical properties, and especially the ductility of heat treated rivets (fabricated from thermomechanically heat treated wire), were affected during the time of their storage in aircraft plant warehouses. To carry out this research we used 5mm diameter 2024 (Al-Cu-Mg) aluminum that had been heat treated using developed technology (solution treatment and artificial aging at the standard regimes). Then, after a certain period of time, specimens were prepared for stretching (3mm diameter), shear (20mm long), and compression (10mm long) tests. For each of the tests 10 specimens were made. These were tested at the following time intervals (from the date of the heat treatment of a wire): 5 days; 30 days; 90 days; 180 days; and 360 days. The Table (opposite) shows the summary data on the effects of aging at room temperature for various intervals on mechanical properties and ductility of the heat treated wire processed by both standard and suggested heat treatments.

The data verify that the wire’s ductility after the TMHT process, even after aging at room temperature for a year, remains much higher than that of a wire processed with standard technology. This can be explained by the crushing of insoluble intermetallic inclusions of manganese (the only el-
A component that prevents crystallization in 2024 aluminum during the wire drawing immediately after quenching.

The ductility of the wire after standard heat treatment remains constant only within one month of aging at room temperature, but the level of ductility of the wire after the TMHT process is much higher and remains constant within three months of aging at room temperature.

Analyzing the Data

From the acquired data we were able to reach the following conclusions:

- The TMHT process for 2024 aluminum wire considerably increased the ductility of the rivets formed from it without a reduction of mechanical properties.
- Aging the heat treated wire at room temperature results in additional aging, which is evident from the increasing tensile strength, yield strength, and reduction of ductility in the alloy. The most significant increase of mechanical properties is observed at natural aging during 90 to 180 day period. This same result was observed for 2024 aluminum alloy.

### Effects of aging at room temperature for various intervals

<table>
<thead>
<tr>
<th>Aging, days</th>
<th>TS, MPa</th>
<th>YS, MPa</th>
<th>Elongation, %</th>
<th>Reduction in area, %</th>
<th>Shear stress, MPa</th>
<th>CW, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>408 (396)</td>
<td>274 (281)</td>
<td>28.3 (25.5)</td>
<td>58.0 (53.1)</td>
<td>257 (254)</td>
<td>81.4 (76.2)</td>
</tr>
<tr>
<td>30</td>
<td>414 (407)</td>
<td>282 (289)</td>
<td>27.9 (24.2)</td>
<td>57.7 (53.4)</td>
<td>267 (261)</td>
<td>81.0 (76.2)</td>
</tr>
<tr>
<td>90</td>
<td>420 (413)</td>
<td>288 (286)</td>
<td>27.3 (25.0)</td>
<td>56.9 (52.2)</td>
<td>266 (261)</td>
<td>80.9 (74.8)</td>
</tr>
<tr>
<td>180</td>
<td>437 (434)</td>
<td>301 (310)</td>
<td>26.4 (23.8)</td>
<td>55.2 (52.1)</td>
<td>273 (261)</td>
<td>78.8 (72.4)</td>
</tr>
<tr>
<td>360</td>
<td>430 (418)</td>
<td>300 (300)</td>
<td>26.5 (23.6)</td>
<td>56.0 (52.7)</td>
<td>276 (275)</td>
<td>79.2 (72.0)</td>
</tr>
</tbody>
</table>

Figure 1 — Microstructure of the bolted joints made from high strength 2024 aluminum alloy: the dark area is a bolt, the light area is a nut made of 2024 aluminum; (inset) the body of the bolt — small black spots are antircrystallizing elements. The bolt has been heat treated by the TMHT process.
observed for wire treated with either standard or TMHT processes. However, the degree of ductility reduction of wire heat treated by the standard technology was much higher than for wire heat treated using TMHT.

- TMHT processed wire has higher ductility (180 days of aging) than that processed with standard heat treatment, despite the increased tensile strength and yield strength of the heat treated aluminum alloy during natural aging at room temperature.

- The acceptable two-month (after quenching) shelf life of 2024 aluminum rivets is justified, since the ductility of the wire using standard heat treating (and the rivets fabricated from it) is constant only within the first 30 days of treatment. However, we observed increasing strength characteristics after 90 days of natural aging.

- Using the TMHT process eliminates all the previously mentioned restrictions and the acceptable shelf life of the rivets can be increased up to one year.

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Conclusions
The analysis of our results allow us to draw the following basic conclusions:

- The ductility of 2024 aluminum specimens using TMHT was considerably high than those specimens of wire made using the standard technology. Moreover, despite the inevitable process of aging while keeping the TMHT-processed wire at room temperature, its ductility exceeded that of standard-processed wire even after one year of aging.

- Using TMHT on 2024 wire to increase its ductility does not change its strength characteristics. The shear strength is even higher at 12 MPa.

- The data show that rivets made of TMHT-treated 2024 aluminum can stay in warehouses of aircraft plants without additional quenching longer (up to one year) than rivets processed by standard heat treatment (not more than two months).

- Our results prove the feasibility of using TMHT on 2024 aluminum.

- The TMHT process has the potential to attract interest from aviation and aerospace industries companies using 2024 aluminum rivets and bolts.

The promising results open the possibility that some aircraft joints that use steel bolts may someday be able to use aluminum bolts, which could save up to 200 kg in the weight of an aircraft.

This article was prepared from a paper originally presented by author Sverdlin at the 22nd Heat Treating Society Conference and Exhibition, September 15-17, 2003, Indianapolis, IN. The original paper was entitled Heat Treatment of Aluminum Alloy V65 for River and Bolt Applications.