The goal of this project is to determine the cause of poor hardness uniformities within current Rockwell Hardness B test blocks and to determine a viable alternative alloy. Test blocks were characterized using indentation and microstructural analysis. An alternate alloy, Al 6061, was identified based on material and economic considerations, and various heat treatments were explored to reach the full range of hardness values. The hardness and hardness uniformity of Al 6061 was calculated. Results indicate that the nonuniform hardness levels in current blocks is due to uneven dislocation density. Al 6061 was able to reach nearly the full hardness range with promising hardness uniformities and warrants further investigation to fully replace cartridge brass.

**Project Background**

Buehler manufactures hardness test calibration blocks for the Rockwell Hardness B (RHB) scale, an example of which is shown in Figure 1. They are currently made of cartridge brass and are offered in a hardness range from 0 to 80 RHB. Hardness test blocks are used to calibrate hardness testers and must meet hardness uniformity standards for accurate and reliable calibration. Buehler is observing poor hardness uniformity within RHB test blocks. At hardness levels below 20 RHB, up to 50% of fabricated test blocks do not meet ASTM E18-20 standards; the cause of reduced uniformity was unknown.

To determine the cause of reduced hardness uniformity, microstructural and indentation analysis was performed. An alternate alloy was identified based on the relationship between yield strength, ultimate tensile strength, and hardness; similar properties are necessary for a successful substitute. To validate the alloy’s suitability for replacement, heat treatment processes were developed to reach Buehler’s offered range of RHB hardness values, and hardness uniformities were measured.

**Experimental Procedure**

**Heat Treatment of Al 6061**

Heat treatment of Al 6061 was performed to test if the alloy was able to meet the full hardness range currently offered by Buehler. Al 6061 blocks were annealed at 535 °C for 75 minutes and water quenched before heat treatments to reach specified values, shown in Table 2.

**Hardness Testing & Uniformity Validation**

After heat treatment, samples were polished, and their hardness was measured to ensure appropriate values & to measure hardness uniformity. Hardness uniformity was calculated using the method outlined in ASTM E18-20. The equation used is shown below in Eqn. 2; HR is the hardness range, Hmax is the highest recorded hardness, and Hmin is the lowest recorded hardness.

\[ R_e = \frac{H_{\text{max}} - H_{\text{min}}}{R_{\text{max}} - R_{\text{min}}} \]

Table 2: Al 6061 sample blocks with their heat treatment, average hardness, and ASTM hardness uniformity values.

<table>
<thead>
<tr>
<th>Heat Treatment</th>
<th>Average Hardness (RHB)</th>
<th>Hardness Uniformity (%)</th>
<th>Meets ASTM Standard?</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 hours at 245 °C</td>
<td>-1.5</td>
<td>5.3</td>
<td>No</td>
</tr>
<tr>
<td>1 hour at 260 °C</td>
<td>27.3</td>
<td>1.7</td>
<td>No</td>
</tr>
<tr>
<td>1 hour at 160 °C</td>
<td>31.8</td>
<td>1.7</td>
<td>No</td>
</tr>
<tr>
<td>3 hours at 190 °C</td>
<td>46.6</td>
<td>4.3</td>
<td>No</td>
</tr>
<tr>
<td>46.6</td>
<td>0.4</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

**Results & Discussion**

Sub-0 and 80 RHB hardness levels were obtained, proving that Al 6061 can reach most of the hardness range currently offered by Buehler. The upper end of the range, near 80 RHB, for Al 6061 is well documented in literature, indicating that the material can meet Buehler’s needs for overall hardness range. However, the hardness uniformities did not meet standards set by ASTM E18-20, as many samples have reduced hardness uniformity values.

Lack of uniformity likely stems from quench delay, as our Al 6061 blocks’ hardness levels often differ among samples that were heat treated under the same conditions. Because Al 6061 is strengthened by precipitation strengthening, it is unlikely that grain size or dislocation density is the primary cause of the observed hardness nonuniformity.

**Microstructure Analysis**

Grain size distribution, shown in Figure 3, is more predictive of hardness than it is of hardness uniformity. The good and poor-quality distributions do not differ significantly, indicating that nonuniform hardness is more dependent upon dislocation density than grain size. Dislocation density decreases during recrystallization.

Figure 3. Grain distribution of good and poor-quality cartridge brass test blocks. Grain areas were normalized to a scale of 0 to 1 for observation of grain distribution independent of grain size. Legend: ‘G’ denotes good-quality blocks and ‘P’ denotes poor-quality blocks.

**Conclusions & Recommendations**

The hardness nonuniformity observed within cartridge brass test blocks is due to nonuniform dislocation density at lower hardness levels. This may be due to uneven recrystallization during heat treatment. Al 6061 shows promise as a replacement for cartridge brass. It can reach the full hardness range currently in-use by Buehler. With further process refinement and larger sample sets, the hardness uniformity may improve past that of cartridge brass.