Alternative Materials Identification for Hardness Test Blocks

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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.

This work is sponsored by Buehler, Lake Bluff, IL

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.

Figure 1. Example brass and steel hardness test blocks.

Experimental Procedure

Test Block Samples

Table 1. Cartridge brass test blocks received from Buehler.

RHB Hardness	Hardness Uniformity	Number Received
0	Good	1
50	Good	2
50	Poor	2
60	Good	1
60	Poor	1
80	Good	1

Current test blocks manufactured by Buehler are made of cartridge brass. Good and poor-quality samples were received with hardness levels shown in Table 1.

Indentation Analysis

Optical micrographs were taken of the indentations within the cartridge brass samples. An image-analysis algorithm was written using MATLAB to calculate the size and shape of indentations. The area and circularity of indents were calculated. The area was calculated using pixel-counting in MATLAB and the circularity was calculated using Eqn. 1.

$$Circularity = \frac{4\pi \cdot Area}{Perimeter^2} \quad \text{Eqn. 1}$$

Microstructure Analysis

Samples were sectioned and polished such that the microstructure of the indented surface could be analyzed. Grain size was measured using ImageJ and the distribution was normalized to a scale from 0 to 1 so that the grain size distribution could be observed independent of the size.

Alternative Alloy Selection

The primary criteria used for selecting an alternate alloy were: similar mechanical properties to cartridge brass, commercial availability, and cost. Alloys that do not age-harden were preferentially ranked. Based on these criteria, we selected Al 6061.

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. All 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. Samples within 0 to 45 RHB must have an HR of 1.5 or smaller to be within the standard, and 45 to 100 RHB blocks must have an HR of 1.0 or smaller.

$$H_R = H_{max} - H_{min} \quad \text{Eqn. 2}$$

Results & Discussion

Indentation Analysis

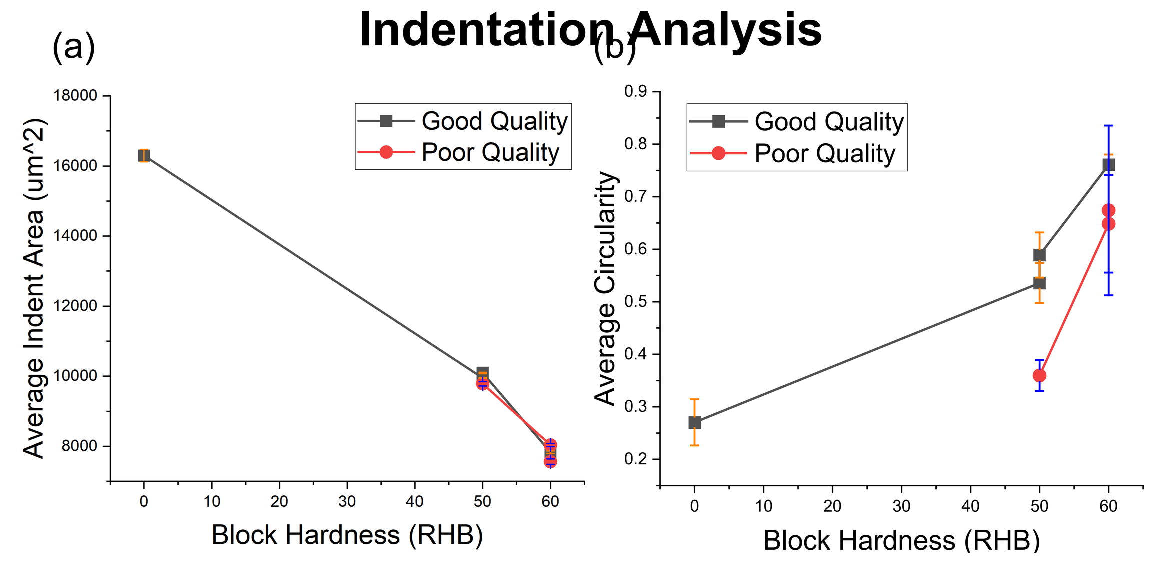

Figure 2. Results of analysis of (a) average indent area and (b) average circularity of indents of good and poor-quality cartridge brass test blocks.

Indentation area, shown in Figure 2a, decreased with increasing block hardness and was not a reliable predictor of hardness uniformity. Indentation circularity, shown in Figure 2b, increased with block hardness and was able to predict the hardness uniformity. The increasing circularity and decreasing area with increasing hardness is due to the increased resistance of the material to deformation. The dependence of circularity measurements on hardness uniformity is due to hardness uniformity's dependence on uniform dislocation density through the material.

Microstructure Analysis

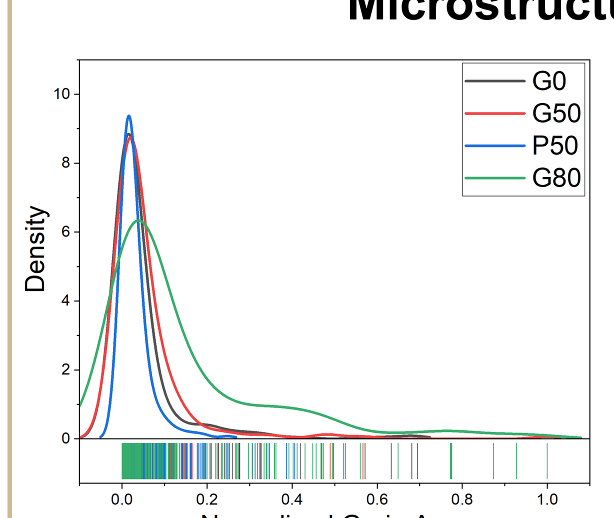

Figure 3. Grain distribution of good and poor-quality cartridge brass test blocks. Grain areas were normalized to a scale of 0 to 1 for observation of grain distribution independent of grain size. In legend, 'G' denotes good-quality blocks and 'P' denotes poor-quality blocks.

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 hardness uniformity is more dependent upon dislocation density than grain size. Dislocation density decreases during recrystallization.

Results & Discussion

Heat Treatments and Hardness of Al 6061

Heat treatment was done using a range of temperatures and times to determine experimental values for the Al 6061 blocks. Table 2 shows individual treatments, the resultant average hardness, and ASTM hardness uniformity values.

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

Heat Treatment	Average Hardness [RHB]	Hardness Uniformity Range	Meets ASTM Standard?
14 hours at 245 °C	-5.5	2.7	No
	-1.5	5.3	No
	4.7	4.2	No
1 hour at 260 °C	27.3	1.7	No
	29.2	2.1	No
1 hour at 160 °C	31.8	1.7	No
	35.1	2.4	No
3 hours at 190 °C	46.6	4.3	No
	59.8	0.4	Yes

Sub-0 and 60 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.

Figure 4 depicts the indentations of Al 6061 heat treated to 4.7 and 59.8 RHB. The observable difference in indentation size and shape further validates the hardness measurements taken.

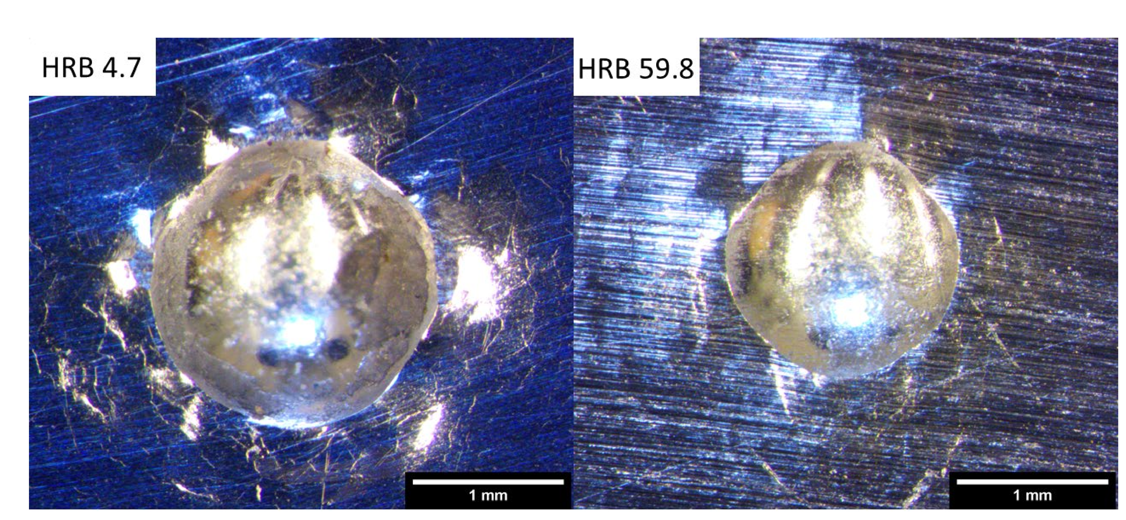

Figure 4. Indentation images of a 4.7 HRB and 59.8 Al 6061 block

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.