Characterization of AlBeMet 162 as an optical substrate material

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Abstract

The use and manufacturing of AlBeMet 162 material as an optical substrate for head mirrors, night vision systems and fire control optics is discussed.

The paper discusses the validation AlBeMet 162's thermal stability over the military environmental temperature range of −40°F to +140°F. The paper will discuss the manufacturing processing to yield dimensional stable optics in AlBeMet material. It will also discuss the results of interferometric testing on 150 mm diameter flats produced by 3 separate optical fabrication companies. Demonstrating the ability of the process and material to produce optical mirrors over temperature with thermal distortions of less than 0.25 wavelengths P-V.

The paper will show interferometrically that AlBeMet and nickel have an excellent coefficient of thermal expansion match over the temperature range of interest, so that there is no bi-metallic issue or distortion due to the electroless nickel.

The paper will also discuss the continuing characterization program with the initial results from testing a light weighted substrates with a spherical surface.

1. Introduction

There is an increasing need in the military and commercial markets for high precision, lightweight, lower cost optical systems with high resolution. Historically these systems have been made from materials such as aluminum, beryllium, metal matrix or a composite. Even though these platforms have performed well in the aerospace arena, there is still a continuing need to reduce weight and cost without penalty to system performance. Over the past years Brush Wellman, through a powder metallurgical process, has developed a material of approximately 65% beryllium and 35% aluminum which has excellent mechanical properties, thermally conductive with an ideal thermal expansion (CTE) closely matching the electroless nickel plating which provides an amorphous surface for optical processing. This material, AlBeMet has been used as structural components for military and space applications and has undergone significant materials properties tests (mechanical, thermal, processing, etc.) and is well documented. Only the optical characterization of the thermal and temporal stability remains an open issue. To this end, Brush has been involved in a modest development program which 1) through the testing of mirrors manufactured from AlBeMet would demonstrate and provide the thermal stability data of the material and 2) a manufacturing process for Brush's customers to use for mirror design in future systems. Temporal stability, the charge in shape of the mirror surface over time, will be addressed in the future as an adjunct to this thermal stability characterizations program. The following sections summarize the requirements and approach to the problem, manufacturing of the test mirrors and measurements of mirror surface distortion over the desired temperature range. Conclusions from the data are presented with a discussion of a follow on phase for a light weighted spherical mirror, which presently is under way.

2. The Approach to the Problem and the Requirements

The initial interest for the characterization AlBeMet was to demonstrate its quality for the use of head mirrors for fire control systems. This characterization would be a validation of the AlBeMet properties. The material is to be used as is with no tailoring of its constituents and a process commensurate to production quantities. All processes shown are routine and are not considered state-of-art and have been performed on various projects by the author and others. The intent is not to make this a science project, but to give the potential user the tools to make stable mirrors from AlBeMet 162. Brush has indicated it is a 100% dense and completely homogeneous. The real unknown is the directional coefficient of thermal expansion (CTE), which plays a major roll in optical stability. Ideally the material should
shrink/expand the same in all direction. The writer cannot argue the point that AlBeMet and beryllium CTE'S are
directionally relatively close in their axes but we are talking about small numbers. The only real way to determine
the thermal distortion is measure the substrate, by optical means. The approach taken is to duplicate the M1-AI, M1-A2
head mirror test conditions by measuring the flatness of a 6-inch AlBeMet disk at various temperature intervals over the
tactical temperature range. The difference in flatness between ambient and the flatness at various temperatures would be
considered the thermal distortion at that given temperature. The allowable change in flatness (for the M1 program) over
any four inch diameter of the head mirror at the temperature extremes of -40°F and + 140°F is 0.5 fringe or 0.25
wavelength (P-V) at 6328 angstroms.

3. Manufacturing of the AlBeMet Substrates

Three suppliers were chosen to make two each of a six-inch diameter electroless nickel plated mirror. The mirror
specification incorporates the engineering practices and processes necessary to manufature a thermally stable
substrate of AlBeMet (see Figure 1). The processes are based on previous work with beryllium and aluminum beryllium.
Two of the three suppliers, Axsys Technologies, Cullman AL, and MRC, Sarasota FL have a long history in the
manufacturing of head mirrors for U.S. and foreign contractors. In addition both suppliers have the test chambers
necessary to measure flatness over temperature. Thales Optronics Ltd of the U. K., formerly Avimo, also participated
even though they do not have a test facility for the stability measurements. Thales made two mirrors in accordance with
the process of Figure 1 and submitted them to Brush Wellman. SSG tested the substrates at their facility in Wilmington,
MA and made the data available for this report.

Both Axsys and MRC were contracted to do three phases of manufacturing and testing of the AlBeMet substrates

Phase 1. Process the Brush supplied substrates in an unplated condition and measure the flatness over
temperature. The information from this configuration determines if the AlBeMet has any anomalies of
its own.

Phase 2. Nickel plate all over and process per the requirements of drawing Figure 1. This is generally
the configuration a mirror would be used in. Measure the flatness as a function of temperature,
identical to Phase 1.

Phase 3. Determine the effect of having nickel on only one side by stripping nickel from backside of
substrate and conduct thermal stability measurements on the mirror surface. Since the CTE of nickel
and AlBeMet are relatively close, it was felt the nickel plating on the back side was possibly not
needed to offset any bi-metallic effect between the nickel plating and AlBeMet substrate.

4. Machining and Thermal Cycling

The processing of the optical substrate is relatively straight forward. AlBeMet machines similar to aluminum, but
somewhat slower do to the dulling of the machine tools. However, there is no progressive machining or acid etch
required as in beryllium. The material maybe machined almost to its final dimensions during the rough machining and
before stress relief is applied. Rough machining to within 0.10 inches of the finished dimensions is acceptable and in
some cases, on non-critical surfaces, the dimension can be finished during the first machining operation. The key to a
stable substrate is in the thermal cycling after machining and during optical processing. It is important the thermal
cycling procedure call out on the drawing in Figure 1 is followed to the letter. The finished mirror may require
additional cycles and processing to demonstrate the part is stable (returns to its original shape and dimensions prior to the
thermal cycling).

5. Electroless Nickel Plating

Polished AlBeMet exhibits significant surface scatter. This type of scatter is inherent in the composite structure and
cannot be eliminated by optical polishing. Typical surface roughness from an AlBeMet polished surface is in the 200 –
250 angstroms finish. To eliminate this phenomenon an amorphous coating such as electroless nickel is required. Surfaces in the 15 to 20 angstrom level are achievable, however depending on the CTE of the substrate material, a potential penalty of bi-metallic effect between substrate and nickel surface is possible. This would reduce the performance of the optic. Previous work done in the tailoring of electroless nickel dictates the phosphorous content in the plating bath needs to be approximately 11% to assure a CTE match close to that of the AlBeMet there by eliminating any bi-metallic effect. The plating process as outlined is covered by a military specification, which is used though out industry.

6. Thermal Distortion Measurements

6.1 Test Chamber Configuration

The testing of the mirror substrates for both Axsys Technologies and MRC were performed in environmental chambers which are dedicated for the testing of the head mirrors on the M1 program. These chambers have been approved by the prime contractor for use on the M1 head mirror program. The test diameter used was four inches, heating and cooling was accomplished by gaseous liquid nitrogen or radiant heaters with internal fans to circulate the chamber air. Thermal couples monitored the substrate temperature to insure the part is at equilibrium prior to making a flatness measurement. Therma's, potential temperature gradients in the substrate and the frosting of the window were a problem from time to time, but could be controlled, producing reliable data. It is felt the over all accuracy of the test set up and the taking of measurements was in the 0.1 to 0.2 fringe range.

The Thales substrates were tested at the SSG's facility, in a thermal vacuum chamber designed for optical component testing. The window in the chamber was capable of handling a wave front diameter of 12 inches. Consequently, the total aperture of the AlBeMet substrate could be tested. Heating and cooling was accomplished by conduction and radiation. Thermal gradients across the substrate were essentially eliminated, leading to ease of measurements and excellent data.

6.2 Thermal Distortion Data

Both Axsys and MRC processed substrates for all three phases 1) Bare AlBeMet, 2) nickel plated both sides, and 3) nickel plated on one side. The bare AlBeMet was difficult to make interferometric measurements do to the scatter from the mirror surface. However, the fidelity of the interferograms were adequate and showed there were no anomalies, such as voids or gross segregation of the constituents, beryllium or aluminum in the substrate.

Tables 1 and 2 show the thermal distortion data for substrates from both Axsys Technology and MRC. Axsys distortion data is in \( \Delta \) fringes as this is their software output, which is the units required by their customer for source inspection for head mirrors. The data easily meets the goal criteria of 0.25 wavelength at 6328 angstroms over a 4 inch aperture.

Included in Table 1 is the substrate distortion data of Axay's S/N 1 substrate with the electroless nickel plating only on the mirror surface. It shows to have less distortion than the same sample substrate plated on both sides. It is felt there is probably little, or no, difference in the distortion between the two configurations. The measurement error in the set ups could easily account for these results.

Thales distortion data is shown in Table 3. The distortion data is for the complete diameter of the 6 inch substrate and is 0.12 wavelengths P-V, or less. These results are nearing the limits of facility measurement capability.

The interferograms, drawings and test equipment used in documenting the data for tables 1, 2, 3, along with distortion data at additional temperatures are on file and are available for discussion through the author or Brush Wellman.

7. Conclusion

All three suppliers have demonstrated that an AlBeMet substrate can be processed to meet the thermal stability
requirements for head mirrors (distortion of 0.25 wavelengths P-V or less over temperature range of -40\(^\circ\) F to +140\(^\circ\) F. Furthermore this data, with AlBeMet 162H's superior properties, indicates that the material is suitable for all reflective imaging systems in both the tactical and selective space sensors arena. (Performance 0.025 - 0.05 rms wavelengths at 6328 angstroms)

8. Future Work

Presently an AlBeMet light weighted F/4 (at the radius of curvature) sphere has been designed and is in the final stages of manufacturing. The substrate processing schedule is identical to the mirrors previously manufactured for the AlBeMet characterization study, just completed. The light weighting is a modest 70%, but it is felt to be adequate to demonstrate thermal stability for a substrate with power in an integral support structure. Thermal distortion measurements are planned for mid to late July 03. If available the distortion data will be presented at the August meeting.

Note: This work was completed in late July 2003. The distortion values measured, which were exceptionally low, may be obtained through the authors or Brush Wellman, Inc.
Figure 1

AlBeMet 162H Mirror
Manufacturing Processing Schedule

1. Material — AlBeMet 162H composition
   --Processed to the standard Brush Wellman procedures
2. Rough Machine to within 0.010 inches of finished dimensions
3. Thermal Stress relieve at 900 - 950°F for 2 hours
4. Finish machined all critical dimensions, allowing for nickel plating thickness.
5. Perform lapping of optical surface to meet all dimensions prior to nickel plating.
6. Perform five (5) thermal cycles -65°C to 150°C per note 7, Brush Wellman drawing D 8808.
7. Nickel plate per Mil–C–2607, class 3. Nominal Phosphorus contents
   11.0 ± 1%
8. Adhesion bake nickel plating at 151.6°C for 1 hour.
9. Thermal cycle 3 times, prior to optical processing, from -65°C to 100°C per note Brush Wellman drawing D 8808.
10. Process the optical surface to the required surface contour, finish and tolerances.
11. Thermal cycle 3 times -65°C to 100°C per note 9 a Brush Wellman drawing D 8808
12. Recheck mirror for optical surface requirements.
13. If part is not in compliance with the optical surface requirements, repeat optical processing and thermal cycling. Recheck part for compliance of the optical surface. Repeat process if required.

Part may be additionally cycled to achieve thermal stability per note 9 Brush Wellman drawing D 8808. Vendors’ discretion.
### Table 1

**Thermal Distortion**  
6.0" Diameter AlBeMet 162 H  
Mirror Substrate 4.0 inch Aperture

<table>
<thead>
<tr>
<th>Temperature (°F)</th>
<th>P-V (Fringe)</th>
<th>RMS (Fringe)</th>
<th>Δ P-V (Fringe)</th>
<th>Δ RMS (Fringe)</th>
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<tbody>
<tr>
<td>+151</td>
<td>0.297</td>
<td>0.058</td>
<td>0.14</td>
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<td>70</td>
<td>0.157</td>
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<td>-47</td>
<td>0.376</td>
<td>0.086</td>
<td>0.219</td>
<td>0.054</td>
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</table>

**Nickel Plating Both Sides (S/N 1)**

**Nickel Plating Mirror Surface Only (S/N 1)**

<table>
<thead>
<tr>
<th>Temperature (°F)</th>
<th>P-V (Fringe)</th>
<th>RMS (Fringe)</th>
<th>Δ P-V (Fringe)</th>
<th>Δ RMS (Fringe)</th>
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<tbody>
<tr>
<td>+150</td>
<td>0.205</td>
<td>0.038</td>
<td>0.079</td>
<td>0.027</td>
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<tr>
<td>70</td>
<td>0.284</td>
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<td>-50</td>
<td>0.396</td>
<td>0.084</td>
<td>0.112</td>
<td>0.019</td>
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</table>

AXSYS TECHNOLOGIES INC.  
Fringe = 1/2λ @ 6328 angstrom

### Table 2

**Thermal Distortion**  
6.0" Diameter AlBeMet 162 H  
Mirror Substrate 4.0 inch Aperture

<table>
<thead>
<tr>
<th>Temperature (°F)</th>
<th>P-V (λ)</th>
<th>RMS (λ)</th>
<th>Δ P-V (λ)</th>
<th>Δ RMS (λ)</th>
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<tbody>
<tr>
<td>+150</td>
<td>0.148</td>
<td>0.028</td>
<td>0.124</td>
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<td>74</td>
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<tr>
<td>-25</td>
<td>0.464</td>
<td>0.0875</td>
<td>0.192</td>
<td>0.052</td>
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</table>

**Nickel Plating Both Sides (S/N 1)**

**MRC**  
λ = 6328 angstroms

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Table 3

Thermal Distortion
6.0" Diameter AlBeMet 162 H
Mirror Substrate 6.0 inch Aperture

<table>
<thead>
<tr>
<th>Temperature (°F)</th>
<th>P-V (λ)</th>
<th>RMS (λ)</th>
<th>Δ P-V (λ)</th>
<th>Δ RMS (λ)</th>
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<tbody>
<tr>
<td>AMBIENT</td>
<td>0.567</td>
<td>0.110</td>
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<tr>
<td>-72</td>
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<td>0.079</td>
<td>0.053</td>
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<td>AMBIENT</td>
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<td>+150</td>
<td>0.635</td>
<td>0.117</td>
<td>0.088</td>
<td>0.02</td>
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<tr>
<td>-49</td>
<td>0.84</td>
<td>0.124</td>
<td>0.12</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Nickel Plating Both Sides (S/N 1)

Nickel Plating Both Sides (S/N 2)

THALES LTD
λ = 6328 angstroms

Note:
Handling Aluminum-Beryllium Alloys in solid form poses no special health risk. Like many industrial materials, beryllium-containing materials may pose a health risk if recommended safe handling practices are not followed. Inhalation of airborne beryllium may cause a serious lung disorder in susceptible individuals.

The Occupational Safety and Health Administration (OSHA) has set mandatory limits on occupational respiratory exposures. Read and follow the guidance in the Material Safety Data Sheet (MSDS) before working with this material.

For additional information on safe handling practices or technical data on Aluminum Beryllium Alloys, contact Brush Wellman Inc.