Appendix to final Report

Task 1: Dewatering: Materials handling of the AMD sludge is very important in making an economical process, but the detailed processing is beyond the scope of this Phase I study. Our objective in Task 1 is to develop a simple reproducible method for collecting the sludge and drying it so that the resulting powders are directly usable in the processing. Further research in dewatering techniques and determination of the cost to produce a usable powder is proposed for future phases of research. While SMPM believes that cost benefit is a key, to the successful commercialization of Fe/Ca, the feasibility of the material must be the focus of Phase I research. SMPM will use thermal methods to dewater the material.

This task was addressed in the final report on the following pages, pages 4 thru 7 and page on page 14. It was found that this process of dewatering is not a viable option. The massive amount of moisture within the sludge created an environment inside the furnace that warped the furnace baffle. The furnace baffle cost approximately $15,000 to replace. Due to this extreme expense a cost analysis for the dewatering of the sludge could not be completed during the Phase I study. An additional study must be completed to determine the cost associated with the dewatering process and possible alternative dewatering techniques.

Task 2: Materials Processing: This task will establish the processing parameters that impact the end product and begin the procedures necessary to quantify the envelope of conditions that are required to manufacture a marketable product. Grinding, pulverization, particle-size analysis and yield will be further explored. While many of these tests could be conducted within SMPM's equipped laboratory, it will be necessary to outsource some testing that involves expensive equipment, such as a scanning electron microscope. Penn State University's Material Research Institute is equipped to conduct such testing. Over the years, the P/M industry has developed an extensive rapport with Penn State's Materials Research Institute in applied research, resulting in advancements throughout the industry.

Task 2 Objectives:

- Grinding/Pulverizing – Reduced material is ground into a very fine particle size.
- Screen/Classify – Resulting powder is classified by particle size for appropriate distribution. At this stage the material is subject to micrology and chemical composition testing.
- Blending – Powder is blended with lubricant and/or alloying elements. Various blends will be researched as described.
- Pressing – Powder is introduced to tooling, forming transverse rupture bars, tensile bars and bearings.
- Sintering – Additional thermal processing is needed to provide strength to the component. SMPM will choose sintering temperatures most closely associated with the particular element's melting points.
- Impregnation – Oil or other liquids are used to fill the pores of the sintered part to provide life-long lubrication and to reduce friction.

This task was addressed in the final report on the following pages, pages 4 thru 7 and page on page 14. We also addressed this task on page 15 and in attachment 1 of this report.

Task 3: Testing: As the processing parameters are being refined, the resulting products will be tested to correlate and quantify the performance standards with the process parameters in relations to accepted powder metallurgy grades. All testing is done in accordance with industry standards established by American Society for Testing and Materials (ASTM) and Metal Powder Industries Federation (MPIF.) Transverse Rupture Strength (TRS) and K Value (compression strength) will be noted with each mixture by forming the material into test bars. The following characteristics will also be tested: chemical composition, wear testing, coefficient of friction, weight, compression and elongation, abrasiveness, nanostructure, density, porosity, impregnation propensity, malleability, diffraction and additive properties. Results will be noted on the material at 100% strength along with all alloy blends. Bearings will be tested for growth or shrinkage using standard metrology, which is necessary to determine dimensional stability.

Task 3 Objectives:

- Determine microstructure, morphology and chemical composition.
- Through particle-size analysis, determine largest useful particle size and resulting scrap yield. Experiment with scrap particles to determine further potential uses or recycling capability.
- Comparative Fe/Ca analysis at 100% using P/M industry standards versus known characteristics of aluminum, steel and bronze.
- Fe/Ca analysis as an alloy with 60-40 and 80-20 blends.
- Manufacture bearings in each blend for determining fatigue, wear, apparent density, compaction, etc., using the industry-wide Arnold Standard. (The standard was named after Norbert Arnold, who is part of the research team.)
- Test bearings for oil capacity, porosity and K Value.
- Study metrology of bearings from green to sintered.
- Provide a baseline standard of results conducive to identifying Phase II objectives.

This task was addressed in the final report on the following pages and dates.

Page 15, March 2, 2006

Page 17, February 15, 2007 & March 1, 2007

Pages 18, 19 and 20

Page 21, April 5, 2007

Page 24, September 10, 2007 & October 3, 2007

Page 25, November 8, 2007

Attachment 2

Task 4: Microstructure Characterization: As the processing parameters are refined and the preliminary testing has begun to clarify range over which useful products are being manufactured, the processing parameters and test results will be correlated with the microstructure of the end product in order to establish a firm scientific basis for the materials performance and to serve as the starting point for continued product quality improvements.

This task was addressed in the final report on the following pages and dates.

Page 15, April 2, 2006

Page 23, June 25, 27, 28 and July 11, 2007

Page 24, July 19, 26, and August 9, 2007

Task 5: Cost Feasibility as Incidental to Phase I: As a component of testing, team members will determine the ultimate conditions of rate and temperature of the sintering furnace used in manufacturing the components, which will establish optimum throughput, as an incidental finding to Phase I testing. Using ASTM standards, the throughput is used to determine cost feasibility; early estimates of cost-benefit can be predicted at this point. However, it is expected that throughput will be further explored in Phase II research by increasing the variable conditions for rate and temperature.

The sludge that is extracted daily from the Brandy Camp mine drainage system, could plausibly be use in the powdered metal production facilities around the region. We have supplied schematics for a functional bearing created from the sludge along with the data collected from the life testing of the bearing, as compared to a commonly used powder metal bearing that was used as a control for the testing. However, it has not yet been determined whether the cost associated with the bearing production would be financially conducive to the lower end market that a bearing of this composition would draw. To determine whether or not the sludge bearing is a marketable item a Phase II study would have to occur that would include a Cost-Benefit Analysis including the following areas.

- The cost associated with the transport of the sludge.
- The cost associated de-watering.
- Processing costs.
- The cost associated with other scientific studies, including metallurgical.
- The cost associated with administrative and political questions concerning the production of usable raw material from acid-mine discharge.

However, if DEP were to supply a powder metal house with dewatered sludge, bearing production could occur. Due to the additional metal added to the bearing the price would fluctuate with the powder market, so a price estimate on the part is not feasible at this time. It has been determined that the DEP could save on shipping cost if it were to dehydrate the sludge prior to exportation to the other blending sites. By dehydration the overall amount of sludge can be reduced by up to 90%. Fifty pounds of wet sludge will produce on average five pounds of sludge powder.