2

SAND--93-3862C

ADVANCES IN RAPID PROTOTYPING*

Conf-9404133--1

Clinton L. Atwood
Gerald D. McCarty
Brian T. Pardo
Edwin A. Bryce

Rapid Prototyping Laboratory, 2484-1
Sandia National Laboratories
Albuquerque, NM 87185-0958

ABSTRACT

Recent advances in stereolithography and selective laser sintering have had a significant impact on the overall quality of parts produced using these rapid prototyping processes. The development and implementation of 3D System's QuickCast™ resin and software for building investment casting patterns have proven to be major steps toward fabricating highly accurate patterns with very good surface finishes. Sandia uses patterns generated from rapid prototyping processes to reduce the cycle time and cost of fabricating prototype parts in support of a Sandia National Laboratories managed program called FASTCAST. As participants in the Beta test program for QuickCast™ resin and software, we experienced a steep learning curve and were able to build accurate parts in a short period of time. It is now possible, using this technology, to produce highly accurate prototype parts as well as acceptable first article and small lot size production parts. We use the Selective Laser Sintering (SLS) process to fabricate prototype wax patterns for investment casting. DTM Corporation recently introduced the use of their polycarbonate material for fabricating investment casting patterns. The polycarbonate material is processed significantly faster, with improved strength, dimensional stability, and without a support structure during the build process. Sandia is currently changing from investment casting wax to polycarbonate for the fabrication of investment casting patterns using the SLS process. This presentation will focus on our successes with these new materials from the standpoints of application, accuracy, surface finish, and post processing. Also presented will be examples of parts manufactured by these processes.

* This work was supported by the United States Department of Energy under contract DE-AC04-94AL85000

gtb

BACKGROUND

A responsibility of the Manufacturing Technologies Center at Sandia is the manufacture of prototype mechanical and electro-mechanical components using state-of-the-art manufacturing processes. These processes have evolved over the years from labor-intensive, manually operated machine tools to computer-aided machining centers and wire-feed electrical-discharge machines. The integration of rapid prototyping processes into the design iteration process has had a significant impact on reducing product development cycle time. In 1989, a new program called FASTCAST that integrates computational technologies and experimental data into the investment casting process was initiated at Sandia. The goal of FASTCAST is to reduce the cycle time necessary to produce a high-quality casting. In support of this goal, a method for rapidly producing wax patterns was needed. Using CNC multi-axis machining centers, we began machining investment casting patterns from billets of machinable wax. This method was effective in reducing lead times and patterns were dimensionally accurate, but the cost of these patterns was excessive. Subsequently, the acquisition of rapid prototyping processes has had a significant and timely impact on manufacturing prototype parts, particularly regarding casting patterns.

STEREOLITHOGRAPHY

A Stereolithography Apparatus (SLA-250) was purchased at Sandia in 1990 as a design tool to facilitate the prototyping process. The initial use of the SLA-250 was to quickly fabricate prototypes from a three-dimensional solid model. Typical uses of the prototype models were proof-of-concept, design review, fit-check, and visual aids for other methods of manufacturing. This process is not a replacement for traditional maching but is another tool used to speed up the product development cycle. The advantages of this process for fabricating prototypes are unattended operation, ease of fabricating complex geometrically shaped parts, increased design flexibility, reduced lead times and fabrication costs, and more efficient design iteration. The evolution of Stereolithography (SL) has brought about significant changes in the applications of this technology. Parts produced by this process are no longer used only for show-and-tell models. They are now effectively used as patterns for investment casting, sand casting, and soft tooling. Early efforts to use solid SL patterns for investment casting failed using the traditional shell casting method. The coefficient of thermal expansion of solid acrylic patterns is greater than that of traditional investment casting wax. As the shelled solid pattern material was heated during the burn-out cycle, the pattern would expand and fracture the ceramic shell. Recent advances in process development and in the implementaion of QuickCast™ epoxy resin and software have had a significant impact on applications for the SL process. Using the QuickCast™ build style and epoxy resin, it is now possible to build semi-hollow patterns for investment casting. The QuickCast™ epoxy resin and build style minimize the problem of thermal expansion during burn-out and allow the patterns to collapse inward rather than expand outward and fracture the ceramic shell. As with any new manufacturing process, there are many variables associated with using QuickCast™ patterns as a replacement for traditional wax patterns for investment casting. Sandia is currently in the iterative process of defining the sequential steps necessary to produce good castings consistantly using QuickCast™ patterns. Our experience indicates that process modifications from traditional lost-wax processing techniques such as burn-out cycles, venting, and pattern preparation are required to build good molds. Sandia has successfully cast several parts using QuickCast™ patterns, Figure 1.

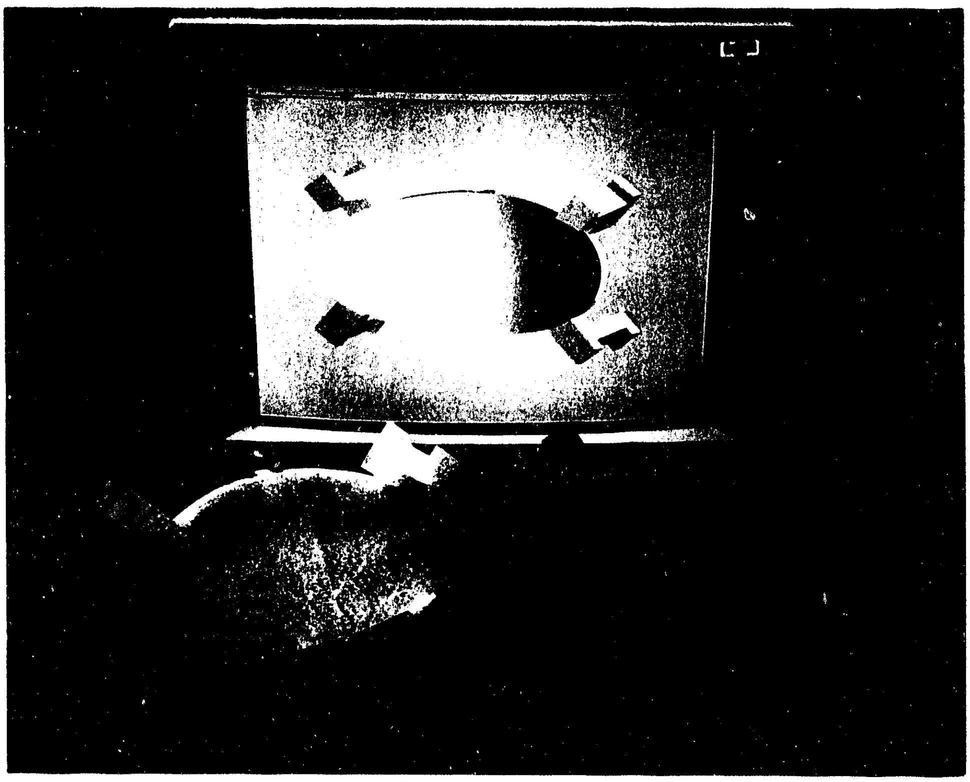

Figure 1 (Top) Three-dimensional CAD Solid Model, (Bottom Left) QuickCast™ Pattern, (Bottom Right) Aluminum Casting

SELECTIVE LASER SINTERING

In March 1992 Sandia became a Beta test site for a pre-production Sinterstation™ 2000 Selective Laser Sintering machine. Our efforts were focused on fabricating the best wax patterns possible using the SLS process. At that time, the SLS process produced the most accurate patterns for investment casting using traditional investment casting wax. Using the SLS process, we were able to demonstrate the value of using rapid prototyping processes to fabricate prototype patterns for investment casting. These patterns were compatible with the traditional investment casting process. At the end of the Beta program, Sandia purchased a Sinterstation™ 2000 SLS Production machine. At that time, a decision was made to change materials from wax to polycarbonate for making investment casting patterns. The advantages of using polycarbonate material are faster build time, more robust parts, dimensional stability, and the absence of a support structure during the build process. Sandia is currently developing techniques required to make investment casting molds from polycarbonate patterns, Figure 2.

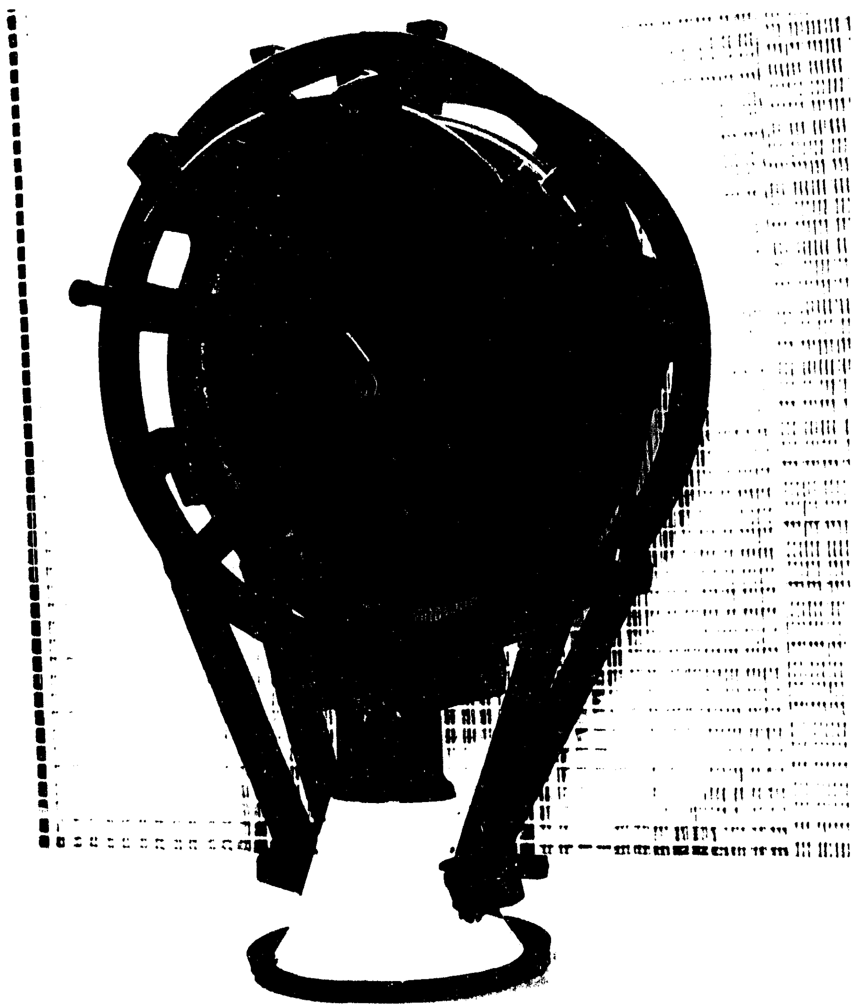

Figure 2 SLS Polycarbonate pattern with wax gating system attached

MEASUREMENT RESULTS OF BENCHMARK PARTS

In an effort to establish the expected accuracy of parts fabricated using the SL and SLS processes, measurements were taken from a benchmark part. The benchmark accuracy part is a bicycle crank arm, Figure 3, fabricated as part of a Technology Transfer program to support a small manufacturer of bicycle components. The geometric shape of the crank arm is representative of a part of average complexity.

The measurement results of the SL acrylic, QuickCast™, and epoxy models, Figure 4, and the SLS wax and polycarbonate patterns, Figure 5, were taken after normal post-processing techniques were used to remove support structures and other excess material after the parts were removed from the machine. These parts were measured in the metrology lab using a Zeiss coordinate measuring machine. A total of twenty-one diameters, twenty-one X-axis and Y-axis locations, thirty radius points, and thirty-eight Z-axis measurements were taken from each part.

This measurement data has been compiled over a three-year period and is an update of previously reported data.

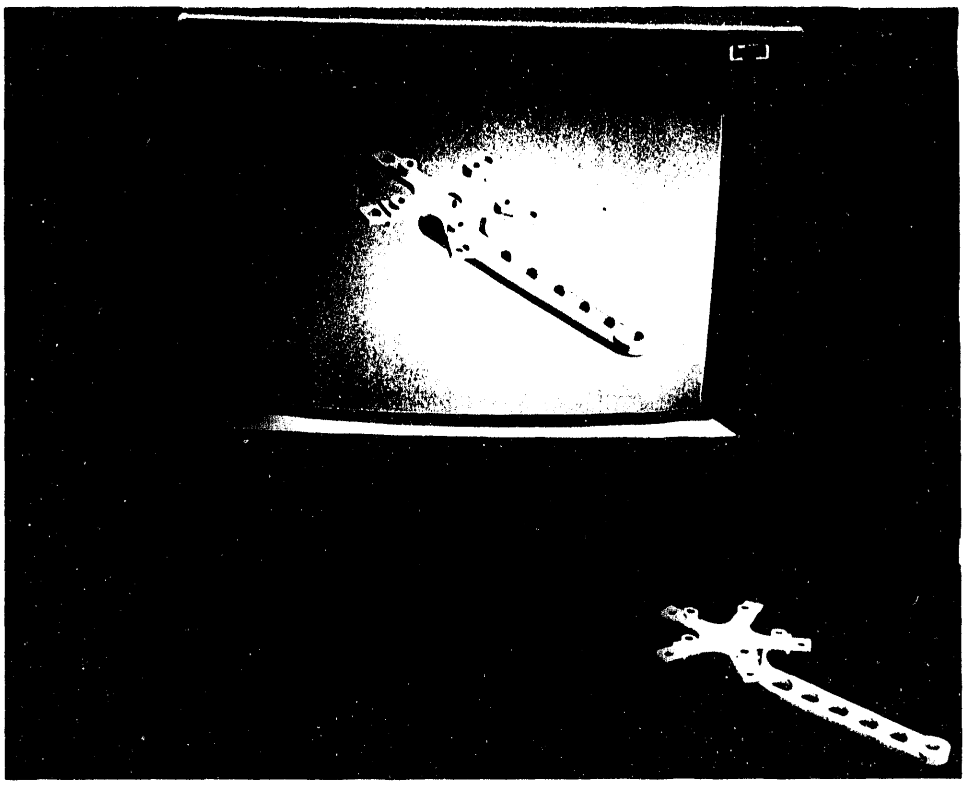

Figure 3 (Top) Three-dimensional CAD Solid Model, (Bottom Left to Right) SLA Fit-Check Model, SLA QuickCast Pattern, SLA Epoxy Model, SLS Wax Pattern, SLS Polycarbonate Pattern

SLA MODELS AVERAGE DEVIATION FROM NOMINAL

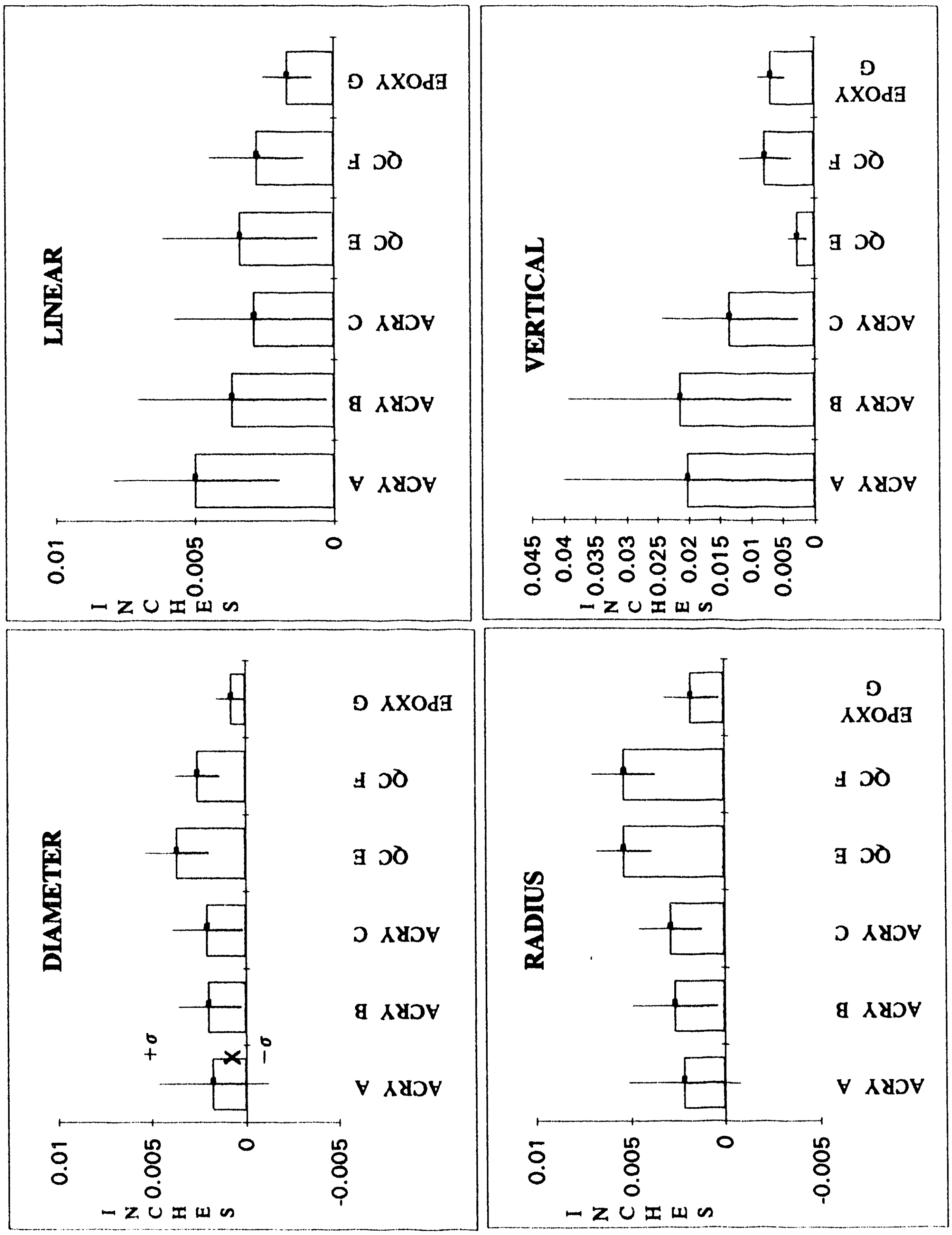

Figure 4 MANUFACTURE DATE: A= 2/8/93, B= 3/22/93, C= 3/24/93, E=6/27/93, F= 6/29/93, G=3/1/94

SLS PATTERNS AVERAGE DEVIATION FROM NOMINAL

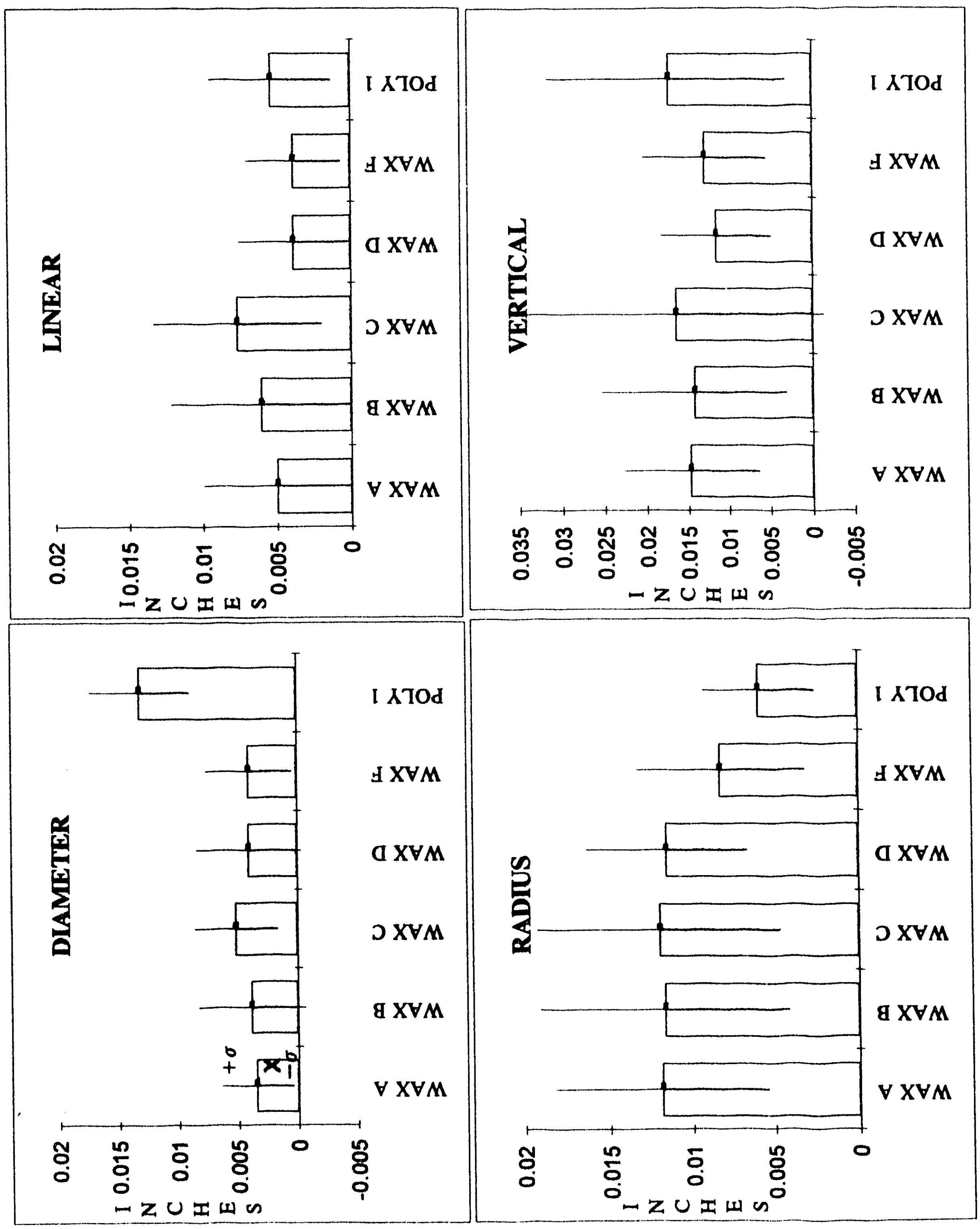

Figure 5 MANUFACTURE DATE: A=9/4/92, B= 9/14/92, C=11/15/92, D= 3/26/93, F= 3/29/93, I= 3/29/94

CONCLUSION

The development and implementation of 3D System's QuickCast™ resin and software has had a significant impact on the overall quality of investment casting patterns fabricated from rapid prototyping machines. QuickCast™ has put to rest the debate over whether SL models could be used as patterns for traditional investment casting. The accuracy and surface finish on patterns fabricated using this process will have a long-term impact on the investment casting industry. Prototype and small-lot production parts are easily attainable without fabricating hard tooling.

Sandia has been using the SLS process to fabricate wax patterns for investment casting since receiving the Sinterstation™ 2000 Beta machine in April 1992. The introduction of polycarbonate as a material for fabricating investment casting patterns will increase the speed and reduce post-processing requirements for pattern processing. The dimensional stability and strength of polycarbonate will facilitate shipping and storage of polycarbonate patterns.

Recent improvements and technological advances in Stereolithography, Selective Laser Sintering, and other rapid prototyping processes continue to create interest in investment casting as a manufacturing process for reducing the product development cycle. Now, any company that owns a Stereolithography Apparatus or Sinterstation™ 2000 can make patterns for investment casting.

REFERENCES

"Integration of Rapid Prototyping Into Investment Casting," Paper No. 23; C. L. Atwood, G. D. McCarty, B. T. Pardo; Sandia National Laboratories, presented at the 40th Annual Technical Meeting of the Investment Casting Institute (1992).

"Integration of Rapid Prototyping Into Design and Manufacturing," C. L. Atwood, G. D. McCarty, B. T. Pardo, E. A. Bryce; Sandia National Laboratories, presented at the SME Rapid Prototyping and Manufacturing '93 Conference.

"Integration of Rapid Prototyping Into Product Development," C. L. Atwood, G. D. McCarty, B. T. Pardo, E. A. Bryce, Sandia National Laboratories, presented at the Towards World Class Manufacturing 1993 Conference.

"Sandia National Laboratory - Accuracy Comparison," Geoff Smith-Moritz, Editor, Rapid Prototyping Report, September 1993.

"FASTCAST," F. Zanner, C. Atwood, M. Maguire, R. Sikorski, D. Gartling, Sandia National Laboratories, Sandia Technology Engineering and Science Accomplishments, 1993.