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INTEGRATION OF RAPID PROTOTYPING INTO DESIGN AND MANUFACTURING[1]

Clinton L. Atwood
Gerald D. McCarty
Brian T. Pardo

Rapid Prototyping Laboratory, 2484-1
Sandia National Laboratories
P. O. Box 5800
Albuquerque, NM 87185

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ABSTRACT

The introduction of rapid prototyping machines into the market place promises to revolutionize the process of producing prototype parts with production-like quality. In the age of concurrent engineering and agile manufacturing, it is necessary to exploit applicable new technologies as soon as they become available. The driving force behind integrating these evolutionary processes into the design and manufacture of prototype parts is the need to reduce lead times and fabrication costs, improve efficiency, and increase flexibility without sacrificing quality. Sandia utilizes stereolithography and selective laser sintering capabilities to support internal design and manufacturing efforts. Stereolithography (SLA) is used in the design iteration process to produce proof-of-concept models, hands-on models for design reviews, fit check models, visual aids for manufacturing, and functional parts in assemblies. Selective laser sintering (SLS) is used to produce wax patterns for the lost wax process of investment casting in support of an internal Sandia National Laboratories program called FASTCAST which integrates experimental and computational technologies into the investment casting process. This presentation will provide a brief overview of the SLA and SLS processes and address our experiences with these technologies from the standpoints of application, accuracy, surface finish, and feature definition. Also presented will be several examples of prototype parts manufactured by the stereolithography and selective laser sintering rapid prototyping machines.

BACKGROUND

Beginning in the early 1940's Sandia has manufactured prototype component parts using state-of-the-art manufacturing methods. The state-of-the-art has progressed from the use of manual machine tools to template guided machine tools to computer aided CNC machining centers and wire-feed, electrical-discharge machines. Sandia uses the investment casting process to fabricate geometrically complex metal parts that are not

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suitable for other methods of manufacture. In 1989, a new concept called FASTCAST for rapidly manufacturing production-like prototype metal castings was initiated at Sandia. In support of this effort, a method for rapidly producing wax patterns was needed. Using CNC multi-axis machining centers, wax patterns for investment castings were machined from solid billets of wax. This method was effective in reducing lead times and patterns were dimensionally accurate, but the cost of the patterns was excessive. The acquisition of rapid prototyping processes has had a significant and timely impact in manufacturing prototype parts, particularly regarding the production of wax patterns.

DESIGN ITERATION PROCESS

The first step in the component design process is the creation of a part design, or the modification of an existing design, by a design engineer, based on customer requirements. This is accomplished by using a computer work station and CAD modeling software to create a solid model. Using solid modeling in the design process has many advantages. The designer can perform engineering analysis, fit-check mating parts, see a three dimensional representation of the design, change the design as necessary, document changes immediately, and retain the design information indefinitely.

After the design is established, the designer may choose to have a prototype part built. If the design is final, manufacturing may proceed using traditional methods and the required material. If the design is not final, the CAD model data is translated to a standard machine readable format. The output from this translation is a Stereolithography (.STL) file. The part is then fabricated using a Stereolithography Apparatus (SLA). The SLA process uses a laser to scan and photocure a thin cross section (.005-.020 inch) of the part geometry and fabricates the part layer by layer until complete. The resulting acrylic model can be used for proof-of-concept, design review, fit-check, visual aid for other methods of manufacturing, patterns for small batch molds, and functional hardware. The advantages of using this process for fabricating prototypes are ease of fabricating complex geometrically shaped parts, increased design flexibility, reduced lead times and fabrication costs, and more efficient design iteration.

MANUFACTURING

After the design iteration process is complete and a production-like prototype is ready for fabrication, it is necessary to determine the proper method of manufacture. Typically, the proper method of manufacture for the prototype is the same as for the production part. If traditional machining methods are used, the CAD model data file is translated into a manufacturing data file and tool paths are generated. At Sandia, if the method of manufacture is investment casting, the part would enter the FASTCAST process. The designer contacts a FASTCAST engineer and the CAD solid model geometry is modified for investment casting. An .STL file is generated and transferred to the Sinterstation 2000 Selective Laser Sintering (SLS) Beta machine. The SLS process uses a laser to scan a thin cross section of part geometry over a layer of wax powder of the same thickness. Each cross section of geometry is fused to the previous layer of wax powder until the pattern is complete. The wax pattern is then cleaned and sent to the investment casting area where wax gates and vents are assembled to the pattern. The entire pattern assembly is then dipped into a binder material and covered with ceramic powder. This step is repeated several times until the resulting ceramic shell is the required thickness. Next, the shell is placed in a pressurized steam autoclave and the wax pattern is melted from the shell, leaving a mold cavity the shape of the wax pattern. The completed ceramic mold assembly is then taken to the melt lab for pouring of the specified metal. There are many advantages of using the SLS process to fabricate wax patterns for investment casting. The traditional method of fabricating a wax pattern requires the acquisition of an injection mold. This can require several months, cost thousands of dollars, and if the part design changes, the mold can become obsolete. Using the SLS process we are able to fabricate a wax pattern within five days after receiving an .STL file. The designer can now request more complex geometrical shapes, optimize the part design to meet customer requirements, and change the design if necessary. Complex parts can be cast to a near net shape and finish machined. Prototypes can be manufactured and tested by the same methods as production parts.

MEASUREMENT RESULTS OF BENCHMARK PARTS

The benchmark accuracy part is a bicycle crank arm , Figure 1, fabricated for the owner of a bicycle shop through a Sandia Technology Transfer initiative to support small businesses. The geometrical shape of the crank arm is representative of a part of average complexity. A polymer model of the crank arm was fabricated on the SLA-250 to verify the design and as a fit-check part to verify dimensional accuracy. After the design was verified several wax patterns were fabricated using the Sinterstation 2000 SLS Beta machine. The wax patterns were ultimately delivered to the bicycle shop owner who had them cast in titanium.

The measurement results of the SLA acrylic models, Figure 2, and the SLS wax patterns, Figure 3, were taken from parts after normal post-processing (techniques used to remove support and other excess material after the part is removed from the machine). The 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.

CONCLUSION

Rapid prototyping processes have a significant impact on how parts are designed and subsequently manufactured. As these processes evolve and become more accurate, new materials and applications are developed and found; and as more design engineers begin to use solid modeling as a design tool, they will have an even greater impact. At Sandia, the SLS and SLA processes have effectively reduced the turn-around time and cost of producing complex prototype parts. Designers have more flexability to meet cost, schedule, and performance requirements. Designs are finalized without creating engineering drawings and ultimately the entire design iteration process from concept to final product is electronically documented.

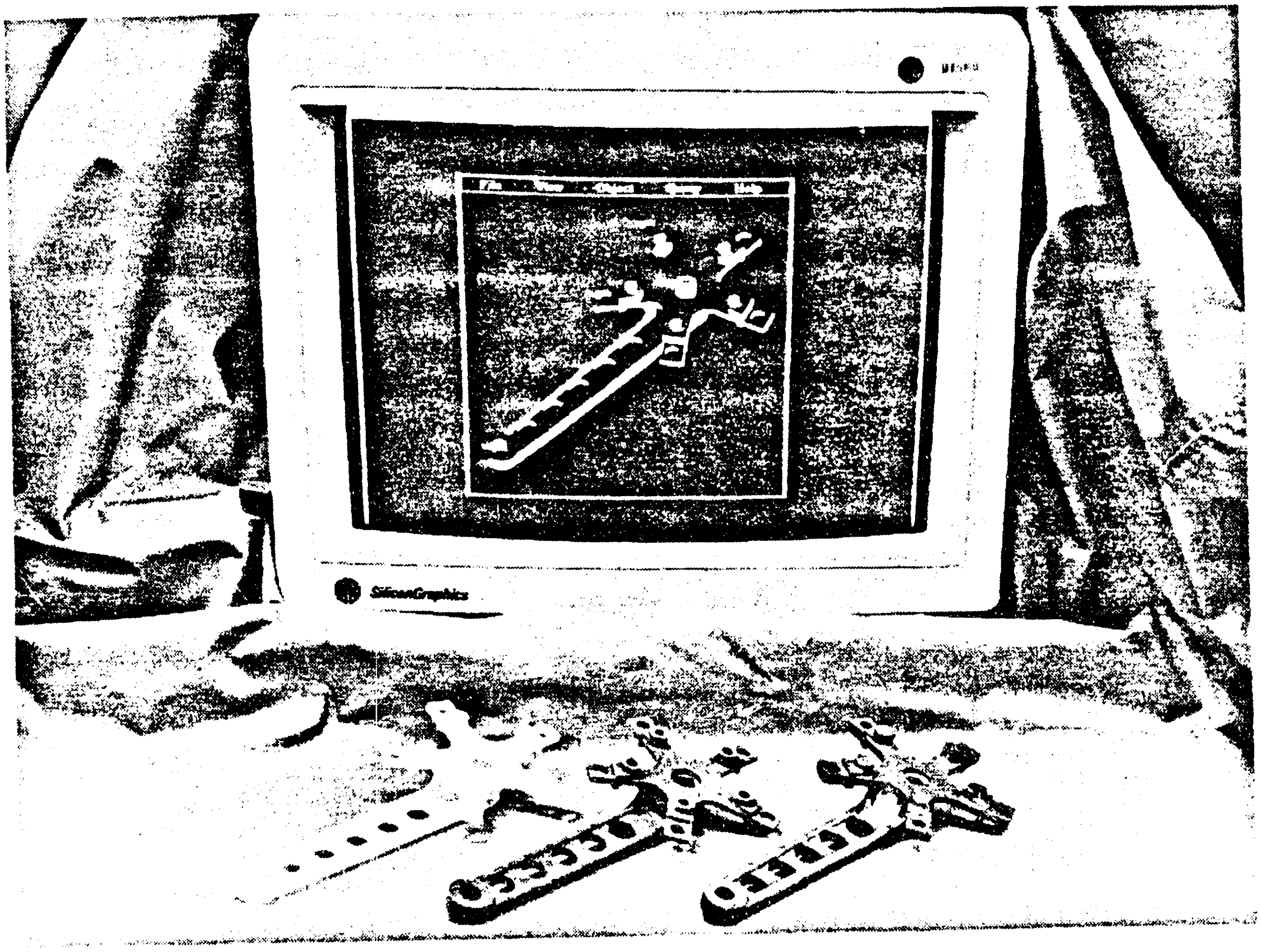

Figure 1 (Top) Three Dimensional CAD Solid Model. (Bottom Left to Right) Acrylic Fit-Check Model fabricated on Stereolithography SLA-250, Wax Pattern fabricated on Sinterstation 2000 Beta SLS Machine, and Titanium Cast Part.

AVERAGE DEVIATION FROM NOMINAL DIMENSION

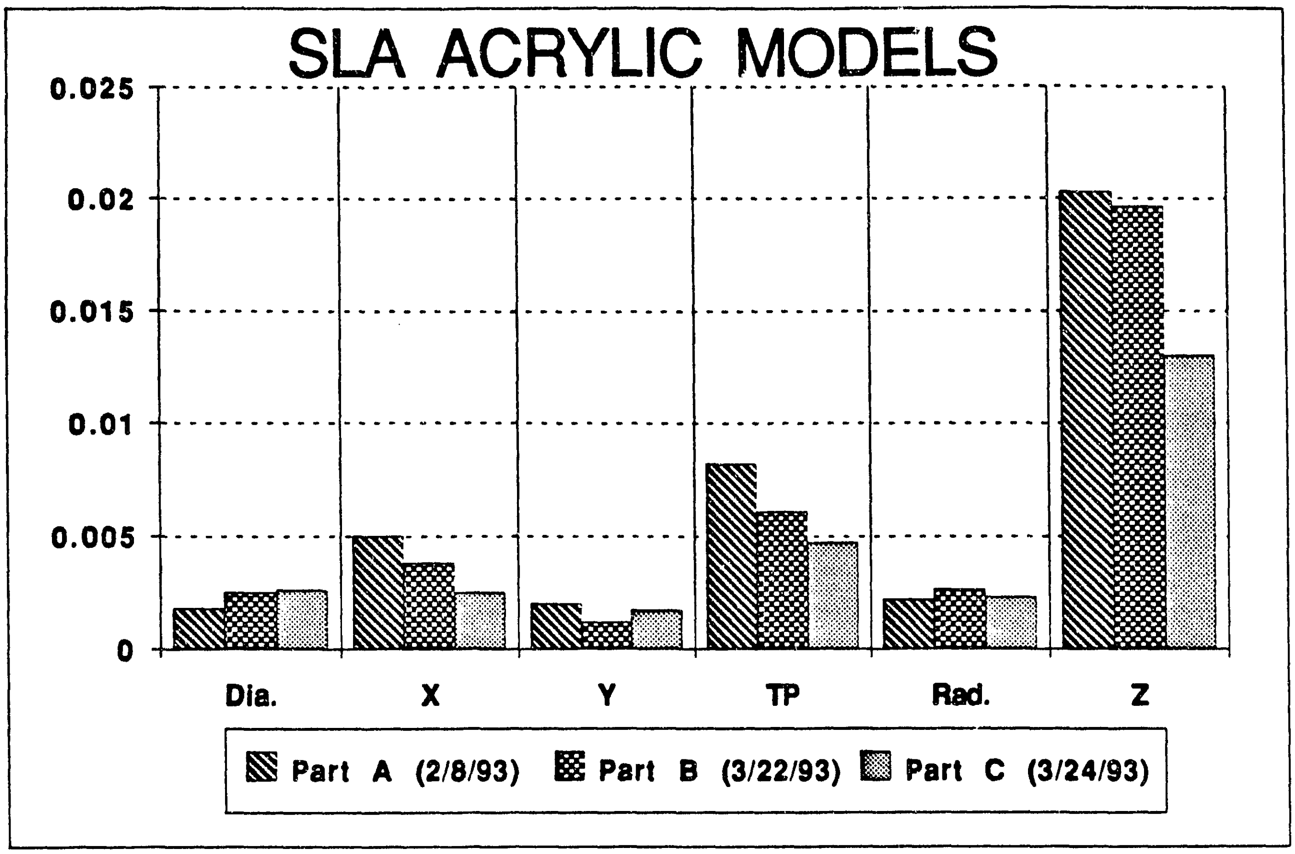

Figure 2 Measurement results of acrylic models.

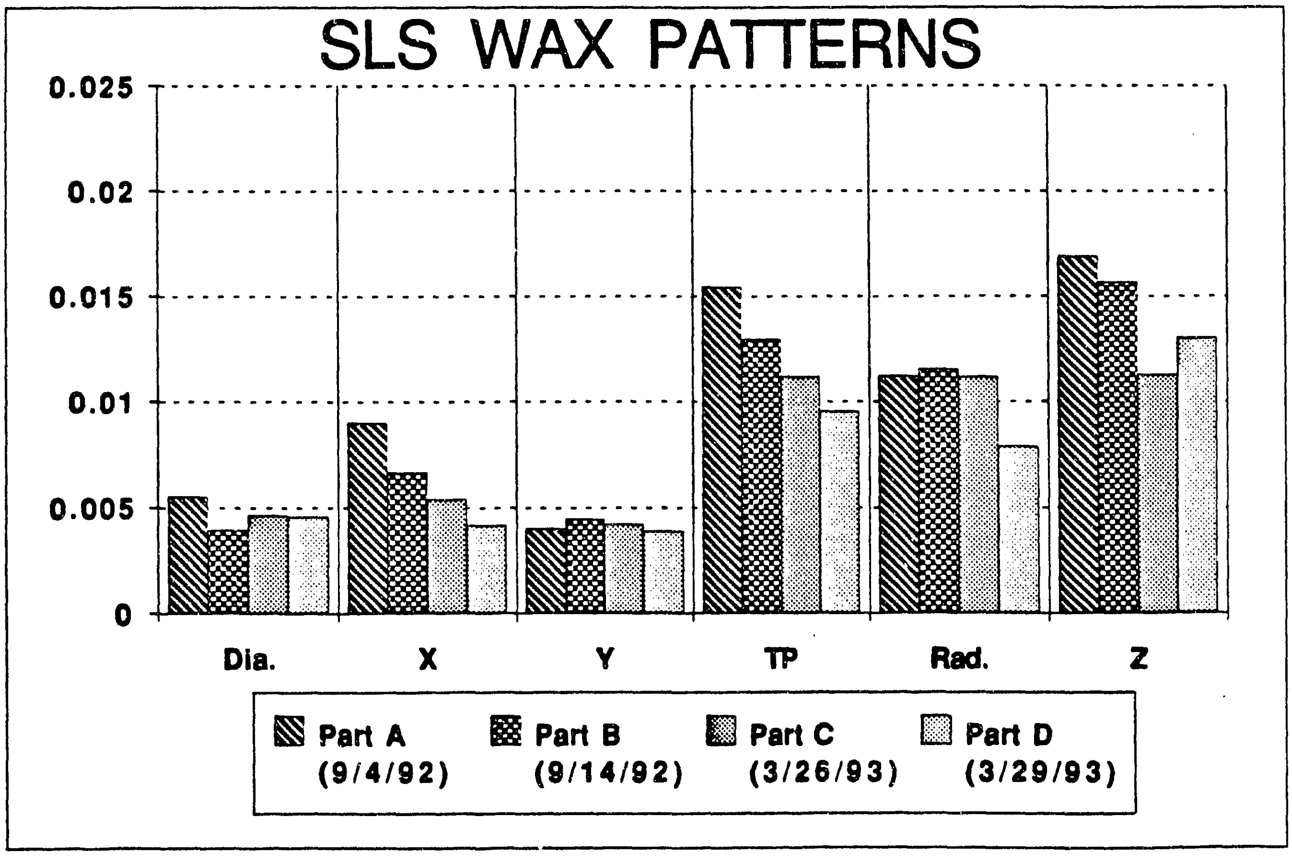

Figure 3 Measurement results of wax patterns.

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