Zirconium Diboride/Copper EDM Electrodes From Selective Laser Sintering

Brent Stucker*, Walter Bradley**, P.T. Eubank***, Somchintana Norasetthekul*** and Bedri Bozkurt***

The creation of electrical discharge machining (EDM) electrodes using freeform fabrication or rapid prototyping (RP) techniques has been the subject of numerous research initiatives around the world[1-6]. Most research projects have focused on finding ways to use RP to reduce the time necessary for producing traditional copper or graphite EDM electrodes. Although making copper or graphite electrodes using RP has potential benefits, those benefits are limited and it is unlikely that a large percentage of EDM users would use RP for producing EDM electrodes of copper or graphite.

If a material superior in EDM electrode performance to copper and graphite could be identified and this material could be made using RP, then users of EDM would be much more likely to use RP methods to make EDM electrodes. Such a material exists. It has been shown that a composite material made up of zirconium diboride (ZrB_2) and copper has an EDM electrode performance superior to any other EDM electrode material ever tested. In addition, a method for making ZrB_2/Cu electrodes using RP techniques has been developed.

Zyrkon™

Previous research at Texas A&M University by Gadalla & Cheng[7,8] had demonstrated that a composite material consisting of zirconium diboride particles surrounded by a copper matrix has superb EDM erosion resistance. That research showed the ZrB_2/Cu composite to be more resistant to wire EDM spark erosion than any other tested material conductive to heat and electricity[9].

Previously, the only published method for producing ZrB_2/Cu was to mix copper and ZrB_2 powders and hot-press them at temperatures in excess of the melting temperature of copper[10]. Hot-pressing, however, is not useful for creating geometrically complex parts. Therefore, a different method for fabricating ZrB_2/Cu electrodes, known as "Zyrkon™" electrodes, in geometrically complex shapes is necessary. Selective laser sintering of polymer coated ZrB_2 powders with post-processing will permit this fabrication[11]. The electrode production path is a four step process, and these steps are summarized in Table 1.

EDM Test Results

Electrodes of Zyrkon™, graphite, copper and W/Cu were tested against steel workpieces to compare their EDM performance characteristics. The graphite electrodes used were EDM-100 graphite electrodes from Poco Graphite. The copper electrodes used were alloy 110 copper bars purchased from McMaster-Carr, with a minimum purity of 99.9%.

---

* Department of Industrial and Manufacturing Engineering, University of Rhode Island
** Department of Mechanical Engineering, Texas A&M University
*** Department of Chemical Engineering, Texas A&M University

The W/Cu electrodes are the standard W/Cu EDM electrodes sold by Intech EDM. They are purported to have a composition of 70%W, 30%Cu by weight. The steel used as workpieces was a type 303 stainless steel purchased from McMaster-Carr.

Table 1 Zyrkon electrode production path

Step #1	Create a powder that contains ZrB_2 and a polymer binder that is compatible with SLS.
Step #2	Use SLS to process the powder from Step #1 into the desired shape.
Step #3	Place the SLS-produced part into a high-temperature, controlled-atmosphere furnace for debinding of the polymer binder and sintering of the ZrB_2 particles.
Step #4	Infiltrate the porous ZrB_2 structure with an appropriate copper alloy utilizing capillary action (minimizing the furnace oxygen content during Steps 3 and 4 is critical).

The Zyrkon electrodes used for the initial tests were produced by cold-pressing polymer-coated ZrB_2 powders instead of using SLS. The rest of the processing steps were identical to those described in Table 1--a sintering temperature of 1700°C and an infiltration temperature of 1200°C was used. (Cold-pressing was used during tests for optimization of the ZrB_2/Cu system because it was cheaper, faster and easier than using RP methods to make the 3/8" x 3/8" x 2" rectangular bars used in the tests.)

The results of EDM tests on these materials can be seen in Figures 3-6. For these tests, a constant off-time of 100μs was used and the on-times and amperages were varied from test to test. Although tests ranging from 8.3 amps to 37.1 amps were performed, only the tests at 14.8 amps are shown due to space limitations. The trends seen at this amperage are the same as the trends seen at other amperages.

A careful look at these graphs indicate that the Zyrkon electrode system is superior to any of the other electrode materials. Zyrkon wear ratios are comparable to W/Cu wear ratios and better than the other electrode wear ratios, but Zyrkon sink rates are much better than W/Cu sink rates. Zyrkon electrode sink rates are comparable to graphite sink rates at low on-times and better than graphite at higher on-times. In the places where graphite is comparable to Zyrkon in sink rate, the wear ratio of the graphite is very poor compared to Zyrkon. Zyrkon electrodes have a higher sink rate than the other electrodes at all conditions. Therefore, when both wear ratio and sink rate are considered, Zyrkon is the best electrode material at every on-time and current.

SLS

In order to make Zyrkon electrodes using SLS, an SLS-compatible polymer coated ZrB_2 powder needed to be created. DTM provided an SLS compatible thermoplastic binder, and it was applied to ZrB_2 powder purchased from Advanced Refractory Technologies, Inc.

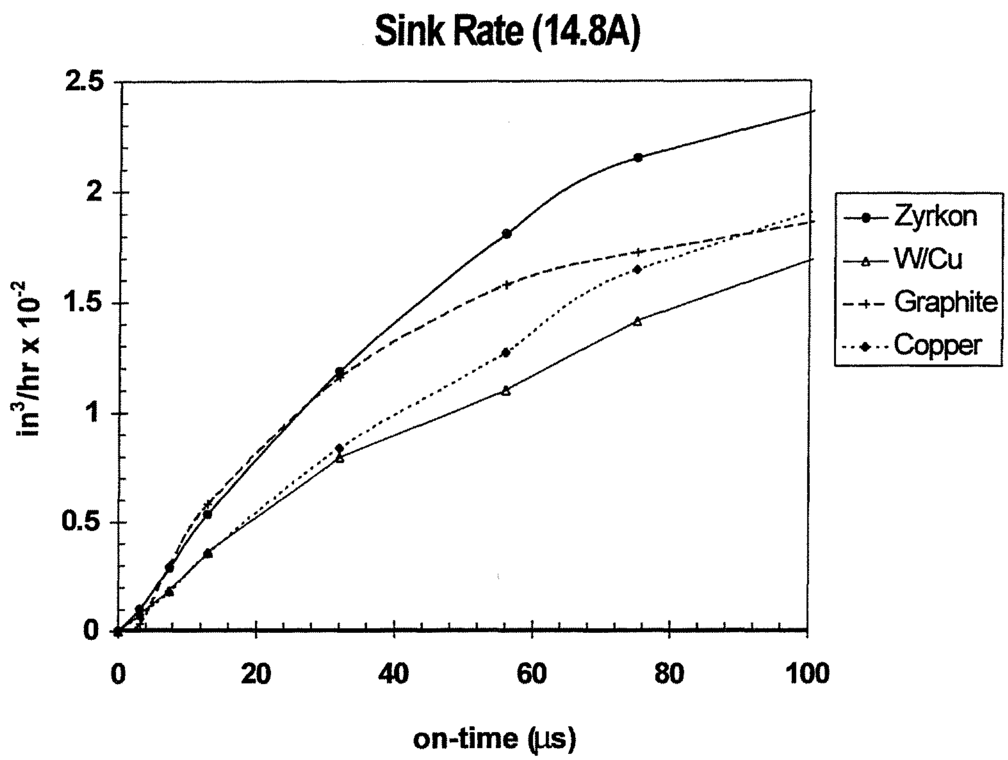

Fig. 3 Sink Rates for various electrodes, 14.8 Amps

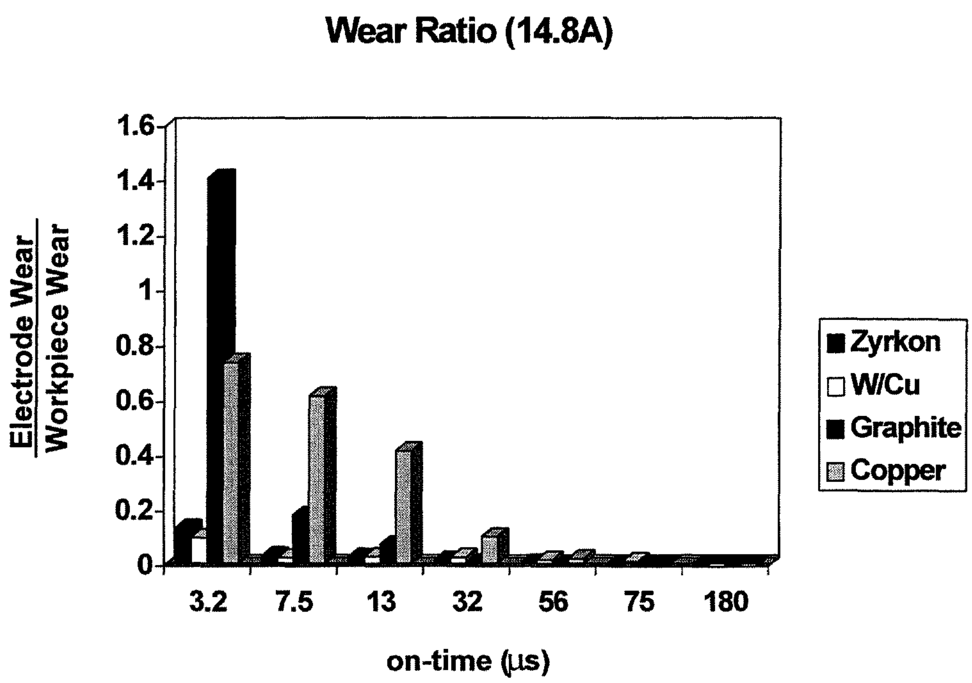

Fig. 4 Wear ratios for various electrodes at 14.8 Amps

using a combination of spray drying and fluidized bed treatment. This combination resulted in ZrB_2/polymer agglomerates that were not very dense. Thus, after SLS processing and binder removal, the resulting sintered parts were only 31% dense prior to infiltration. The cold-pressed parts, on the other hand, had ZrB_2 densities of 55-60% by volume.

The EDM test results using the SLS-produced parts in the electrode testing procedure can be seen in Figures 7 and 8. The on-times of 3.2μs, 7.5μs and 13μs were run at 14.8 amps. The on-times of 75μs and 180μs were run at 24.8 amps. These on-times and amperages were chosen to mimic finishing and roughing conditions respectively.

It can be seen from these results that the SLS-produced Zyrkon parts did not perform as well as the cold-pressed parts. This is due to the lower amount of ZrB_2 present in the parts. To verify that this was indeed the case, some of the powder used in the SLS machine was pressed to a higher density of 50%. This powder did perform similarly to the original pressed parts, confirming the hypothesis that it was the lower ZrB_2 amount that caused the reduced performance. However, even though the SLS-produced Zyrkon parts under-performed the pressed parts, they were still as good as or better than any of the other electrode materials.

In order to increase the ZrB_2 content in the SLS-produced parts a new approach to adding the binder must be used. Research is proceeding with the help of DTM to try new dry-mixable thermoset binders. If these binders prove effective, spray drying and fluidized bed treatment steps can be eliminated and the agglomeration density problem can be avoided.

In addition to these EDM tests, qualitative tests were performed on geometrically-complex parts created on the SLS machine and sent to Kodak and Steelcase. The electrode made for Kodak was a copy of a graphite electrode used to make a small spring. This electrode was small and thin, with an EDM electrode surface approximately 1.25" long (if uncoiled) and no greater than 0.0625" thick and 0.025" deep. Two different EDM tests were run using two different electrodes. One was run at 5 amps, 74μs on-time and 20μs off-time. This produced a semi-smooth surface, and the electrode ran with no problems. The other electrode was tested at an extreme current for an electrode this size. It was tested at 18 amps, 50μs on-time and 12-25μs off-time and the electrode and machined workpiece are shown in Figure 9. An identical graphite electrode was also run at the same conditions and is shown with its machined workpiece in Figure 10. Both electrodes produced equally poor surface finishes, but it was observed that the Zyrkon electrode cut faster than the graphite electrode. In addition, the graphite electrode exhibited short-circuiting, arcing, contamination and high electrode wear at these conditions--none of which was true for the Zyrkon electrode.

The electrode made for Steelcase was significantly larger, measuring approximately 1.25" long, 0.75" wide and 0.3" deep. This electrode was used at what they termed, "finishing" and "semi-finishing" EDM conditions. An aluminum block was cut at semi-finishing conditions and is shown with the Zyrkon electrode in Figure 11. A steel block was subsequently cut at finishing conditions and is shown in Figure 12. Several features on the electrode were measured to help determine wear on the Zyrkon electrode, and no measurable wear was found, even after both EDM operations.

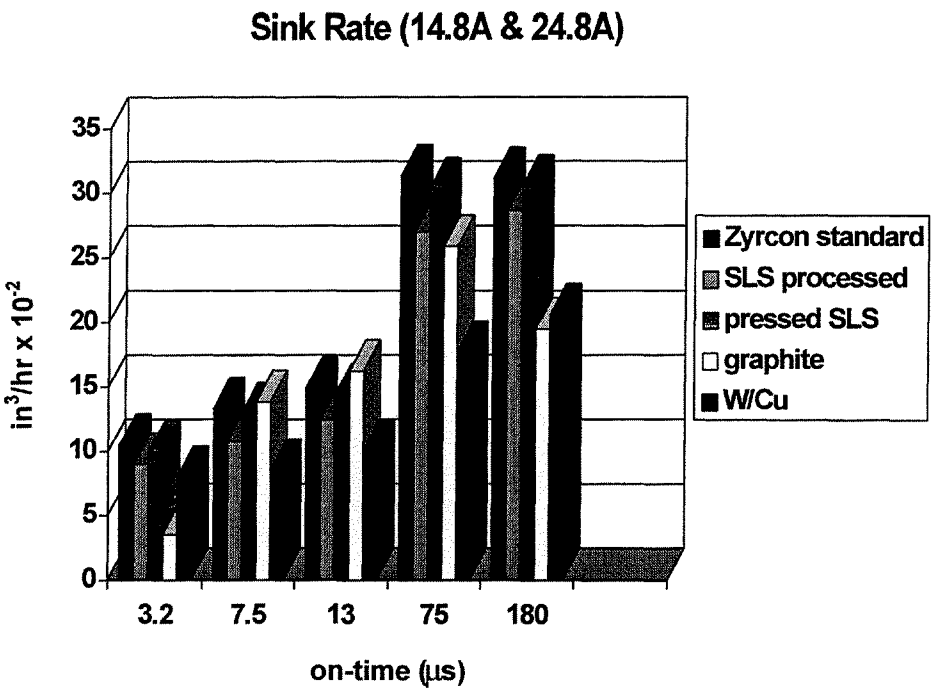

Fig. 7 Sink rates of various electrodes compared to SLS-made electrodes

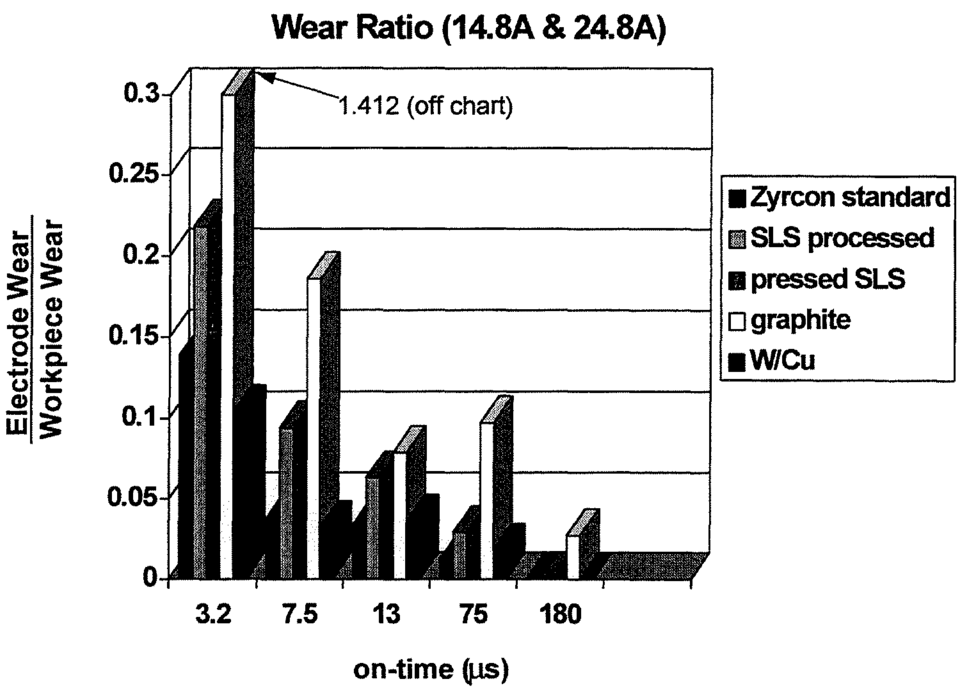

Fig. 8 Wear ratios of various electrodes compared to SLS-made electrodes

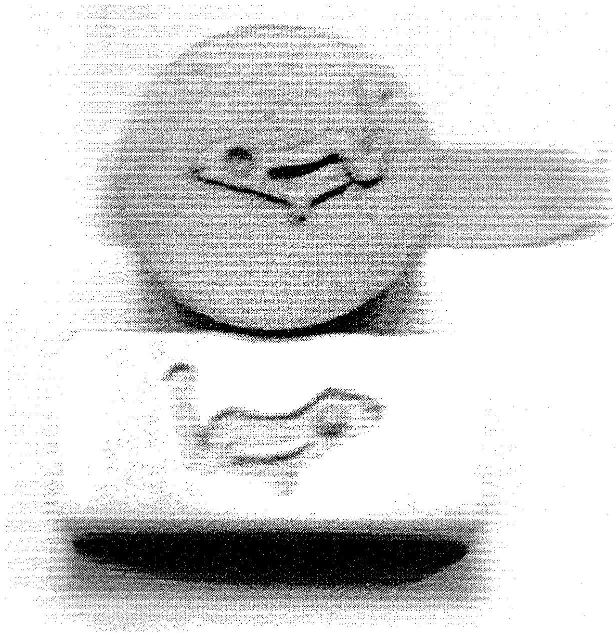

Fig. 9 Zyrkon electrode and steel workpiece after EDM at 18 Amps, 50μs on-time, 12-25 μs off-time (steel workpiece is 1.25" across its greatest dimension)

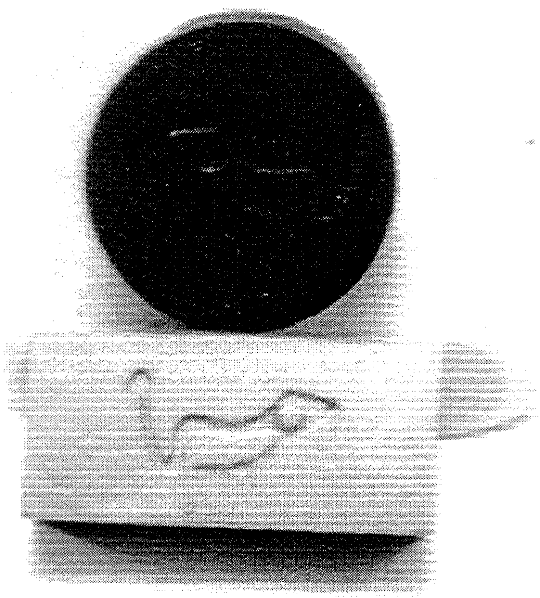

Fig. 10 Graphite electrode and steel workpiece after EDM at 18 Amps, 50μs on-time, 12-25 μs off-time (steel workpiece is 1.25" across its greatest dimension)

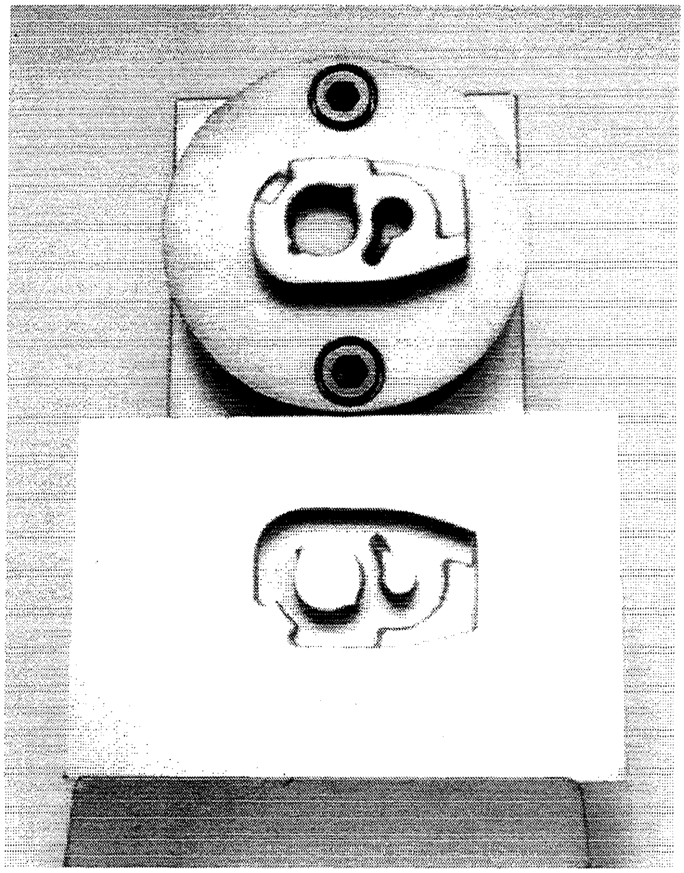

Fig. 11 Zyrkon electrode and aluminum workpiece after EDM at semi-finishing conditions

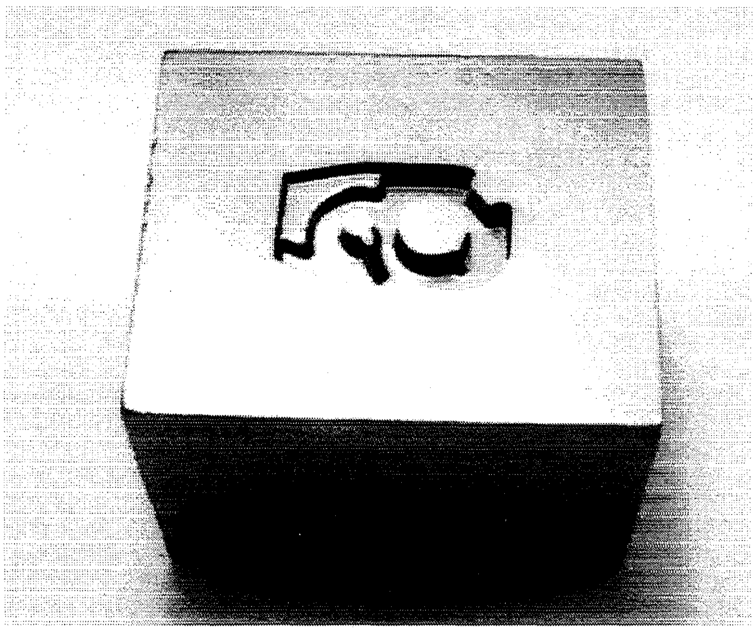

Fig. 12 Steel workpiece after EDM by Zyrkon at finishing conditions

In addition to good wear ratio and sink rate performance, the surface finishes of the cavities produced at Steelcase were very good. The EDM surfaces of both workpieces were surprisingly smooth after the EDM operation. This experiment confirmed the hypothesis that the degree of surface roughness present with current SLS technology is not highly detrimental to the fabrication and use of EDM electrodes.

SLS-produced electrodes, after debinding, sintering and infiltration, without performing any manual finishing except a light bead blasting, have a semi-rough feel, like 220 grit sand-paper. Following the use of these electrodes at semi-finishing and finishing conditions, these electrodes have the feel and look of polished metal. This is because the EDM process erodes the "high spots" on the Zyrkon electrode, giving a smoothing of the electrode with use, and thus, the surface finish it produces on the workpiece. This smoothing of the electrode surface, as observed at Steelcase, did not result in macroscopic dimensional changes.

Conclusions

The results of these studies on Zyrkon indicate several things:

(1) Because Zyrkon is an EDM electrode material that surpasses currently available electrode materials in its EDM performance characteristics, this material will become increasingly popular with EDM users.

(2) Zyrkon can be made using selective laser sintering and initial results indicate that electrodes made using SLS will perform better than traditional electrodes made using traditional techniques. As the binder problems are solved, the performance of SLS-produced Zyrkon electrodes will approach the performance of cold-pressed Zyrkon electrodes.

(3) The processing techniques developed for creating Zyrkon electrodes are compatible with a number of RP processes and molding techniques. Many other techniques for creating Zyrkon electrodes are being examined and a number of these techniques should be available to the public in the near future.

Acknowledgements

This research was made possible by generous funding from the National Science Foundation through grant DMR9420386 and through a National Science Foundation Graduate Research Fellowship, which paid for a significant portion of Brent Stucker's salary. The in-kind and financial support of DTM, Kodak, Advanced Refractory Technologies and Steelcase are gratefully appreciated.

REFERENCES

[1] Arthur, A., Dickens, P., Bocking, C. and Cobb, R., 1996, "Wear & Failure Mechanisms for SL EDM Electrodes," *Solid Freeform Fabrication Symposium Proceedings*, Bourell et al, eds., The University of Texas, Austin, TX, pp. 175-190.

[2] Bradley, W.L., and Stucker, B.E., 1995 "Producing EDM Electrodes with Rapid Prototyping Techniques," *EDM '95 Conference Proceedings*, Chicago, IL.

[3] Ippolito, R., Iuliano, L. and Gatto, A., "EDM Tooling by Solid Freeform Fabrication & Electroplating Techniques," *Solid Freeform Fabrication Symposium Proceedings*, Bourell et al, eds., The University of Texas, Austin, TX, pp. 199-206.

[4] Jensen, K.L. and Hovtun, R., 1992, "Making Electrodes for EDM with Rapid Prototyping." *Industriel Teknologi*, September.

[5] Killander, L.A. and Homer, B., 1996, "EDM Electrodes Made by RPT," *EARP European Action on Rapid Prototyping,* May, No.8.

[6] Stucker, B.E., Bradley, W.L., Norasetthekul, S., and Eubank, P.T., 1995, "The Production of Electrical Discharge Machining Electrodes Using SLS: Preliminary Results," *Solid Freeform Fabrication Symposium Proceedings*, Marcus et al, eds., The University of Texas, Austin, TX, pp. 278-286.

[7] Eubank, P.T., and Bozkurt, B., 1992, "Recent Developments in Understanding the Fundamentals of Spark Erosion for Composite Materials," *Machining of Composite Materials Symposium*, T.S. Srivatsan, D.M. Bowden, eds., Am. Soc. Materials, Materials Park, OH, pp. 159-166.

[8] Gadalla, M.A. and Cheng, Y.M., 1992 "Machining of Zirconium Diboride and Its Composites," *Machining of Composite Materials II Symposium* presented at ASM Materials Week Conference, October 18-21, Pittsburgh, PA.

[9] Cheng, Y.M., 1994, "Synthesis and Electrical Discharge Machining of Advanced Ceramics Containing Zirconium Diboride," *Doctoral Dissertation*, Texas A&M University, College Station, TX.

[10] Cheng, Y.M., and Gadalla, A.M., 1996, "Synthesis and Analysis of ZrB_2-Based Composites," *Materials and Manufacturing Processes*, Vol. 11, No. 4.

[11] Stucker, B.E., 1997, "Rapid Prototyping of Zirconium Diboride/Copper Electrical Discharge Machining Electrodes," *Doctoral Dissertation*, Texas A&M University, College Station, TX.