Development of Direct SLS Processing for Production of Cermet Composite Turbine Sealing Components - Part II

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RESULTS AND DISCUSSION

Indirect SLS

Coupons from each of the compositions shown in Table 3 were fired in vacuum to burn off the binder and fully consolidate the coupons. Shrinkage measurements taken from these coupons placed the shrinkage at 4%-6%. Metallographic evaluations revealed that all samples possessed relatively uniform grit distribution. A typical microstructure is provided in Figure 6.

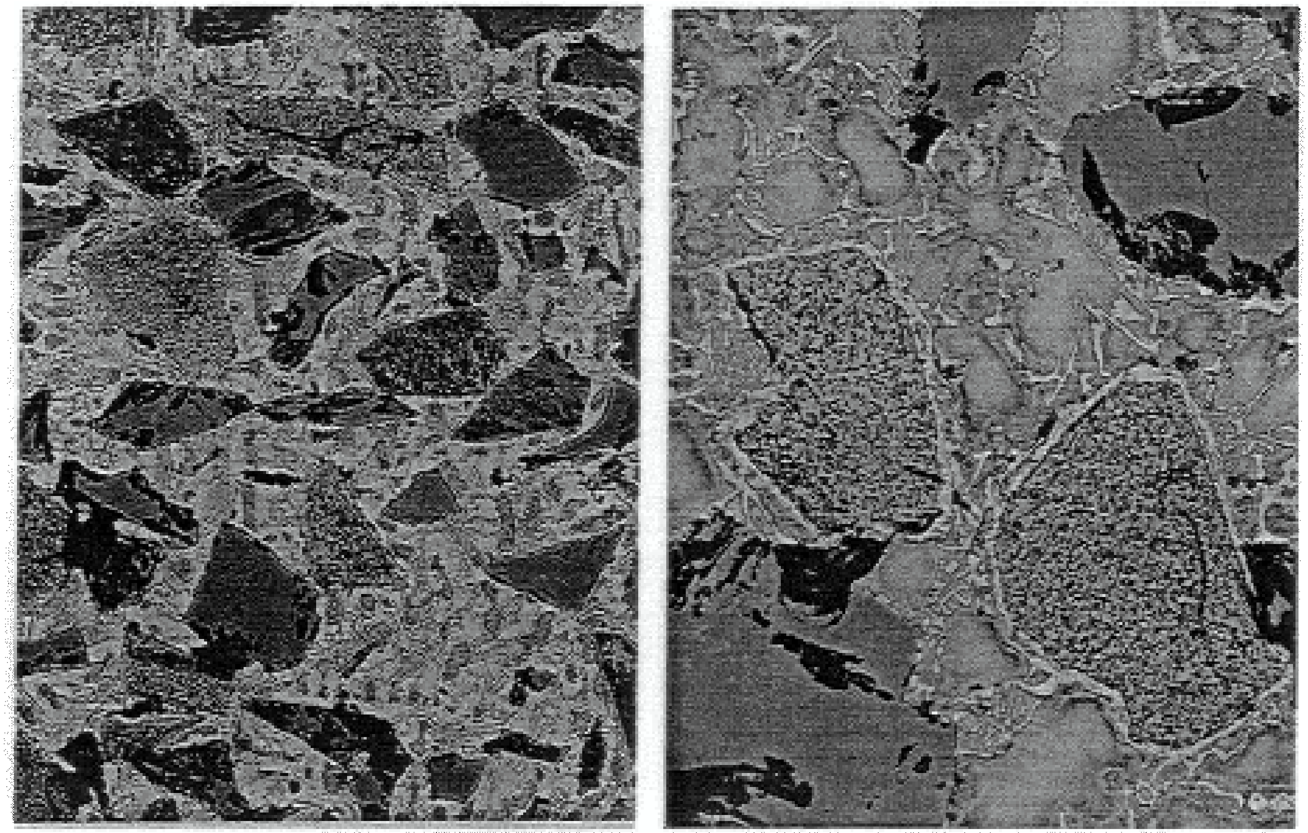

Figure 6. Typical microstructure of indirect processed material, magnifications 100X & 250X

However Compositions # 4 and #5 illustrated substantial pullout of grit particles during polishing.

The microstructures of Composition #4 is provided in Figure 7. In Composition #4 the grit pull out was associated with the reduced braze content and in Composition #5 this was associated with the alumina used which did not have a titanium coating. This experiment effectively illustrated that the titanium coating on the alumina is necessary. The minimum braze content for an indirect process was established at approximately 18% by weight.

Samples of Compositions #2 and # 3 were manufactured according to the process detailed

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above. The samples of Composition #3 had circular patches removed which were surface ground and brazed using a braze alloy into the gage section of a single crystal stress rupture bar. The acceptance criteria requires that the sample survive a minimum of 2100°F/35 hours. The results of the four specimens are provided in Table 4. Only one sample did not meet the qualification criteria, this sample failed at the braze joint, indicating a bond defect.

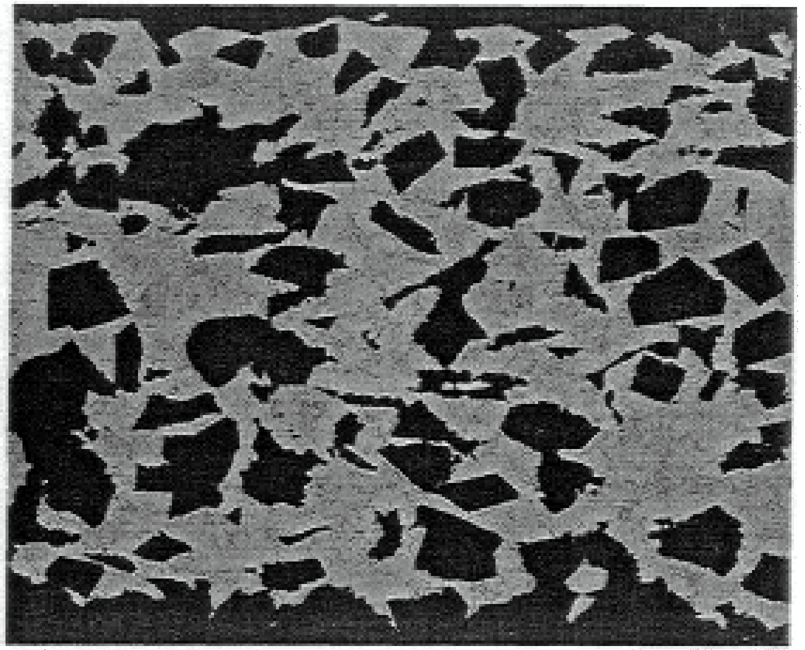

Figure 7. Microstructure of Indirect Processed Composition # 4 illustrating grit pull-out, magnification 100 X

Sample	Stress (psi)	Time (hrs)	Temperature (°F)
3-AM	500	50	2100 48 hrs.
3-BM	500	50	2100 No failure
3-CM	500	50	2100/8.2 hrs. Braze Failure
3-DM	500	50	2100 No failure

Table 4 Stress rupture test results of indirect SLS processed cermet

Rub coupons were also manufactured from the samples and rub tested at room temperature. The results are provided in Table 5. A schematic of a rub test is provided in Figure 8.

Processing	Composition	Volumetric Rub Ratio	Linear Rub Ratio
Indirect	3	170	13
Indirect	2	511	14
Allison conventional	3 Equivalent	140	144

Table 5 Rub testing of indirect processed material against seal material (Quantabrad 2)

Evaluation of room temperature rub testing results on Compositions #2 and #3 provided interesting results. The evaluation involved linear rub ratios which is the ratio of ceramic rub scar depth to abrasive cermet height loss which is not an extremely precise measurement due to the fact that tip height loss, if not significant, is not easily and accurately measured. In general, linear rub ratios in excess of 10 are good and meet abrasive blade tip goals. The indirect SLS materials evaluated met this goal.

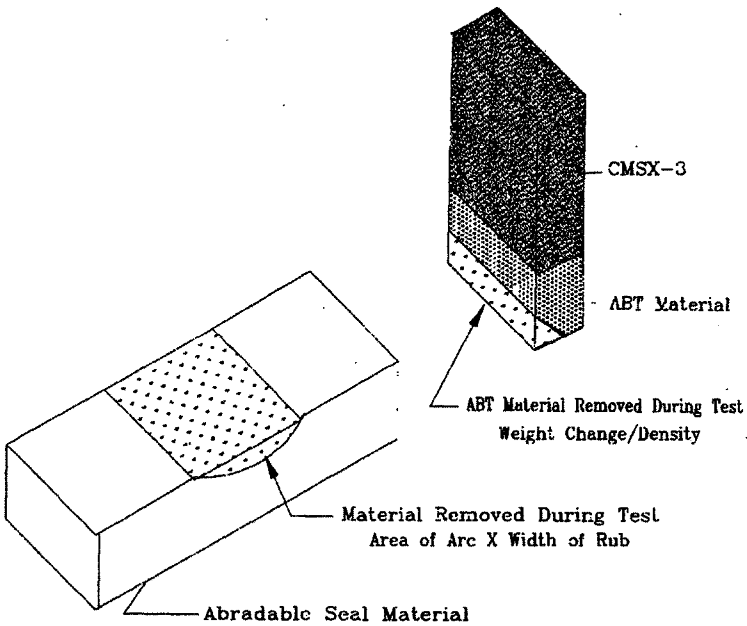

Figure 8. Illustration of Rub Testing

A more accurate measure is a volumetric comparison which is the ratio of rub scar arc depth multiplied by the rub scar width to the tip weight loss divided by the abrasive density. Simply stated this is the ratio of the abradable seal material rub scar volume to the volume lost on the abrasive tip.

As the data indicates, the volumetric comparison provides different results than the linear rub ratio comparison. A volumetric rub ratio in excess of 30 is considered good. The volumetric comparisons indicate the results of the SLS processed material are very good. It is to be noted that all of the above materials would be considered equivalent based on the limited number of tests run. To distinguish one as being better than another, a statistically significant number of tests from different lots of materials would need to be conducted and then reviewed with accompanying stress rupture data.

The testing of indirect SLS processed cermet indicated that it was comparable in microstructure and mechanical properties to the material processed by the standard technique. Therefore a final process demonstration was completed to illustrate that production of blade tips via the indirect process is feasible.

A small lot of material was manufactured to produce 4 pieces of hardware. The parts were laser scanned to final shape accounting for 4% shrinkage. The parts were subsequently fired in vacuum. Two of the four pieces of hardware produced are illustrated in Figure 9. The microstructure of the parts, presented in Figure 10, was very uniform and passed all requirements. As discussed earlier, follow-on development was aimed at volatilizing the binder using low power scans of the laser. These experiments were canceled due to the coating of laser optics and chamber apparatus by the volatilization of the binder.

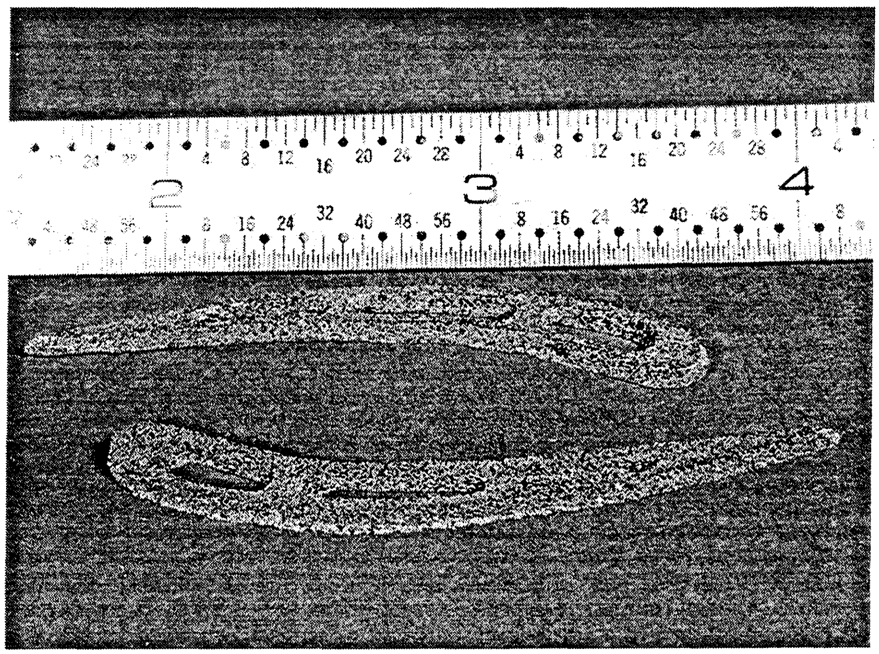

Figure 9. Blade Tips Produced via Indirect SLS Process

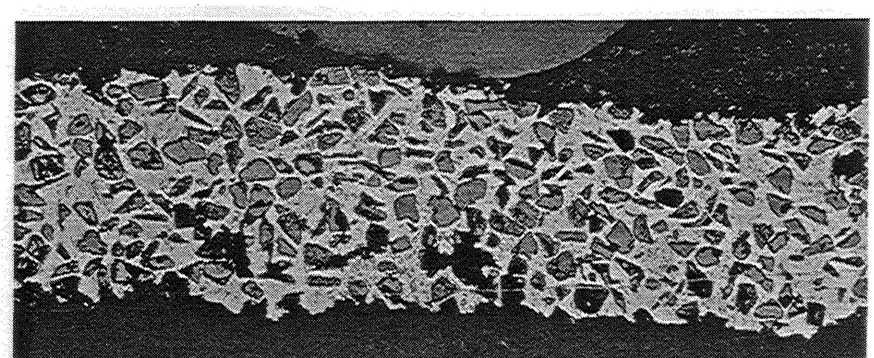

Figure 10. Typical microstructure of Indirect Processed blade Tip, Minimal Porosity and Agglomerates, magnification 25X.

Direct SLS

Direct SLS trials indicated that full through thickness melting was achieved with energy densities of approximately 1400 J/cm^2. However, these samples illustrated porosity entrapped around grit particles. The porosity began to be eliminated when energy density levels were in the 3000 J/cm^2 range. This transition also corresponds with the point at which the microstructure changes from very fine equiaxed to dendritic. Examples of the changes in microstructure are provided in Figures 11 through 13. It is interesting to note that the very fine grained microstructure, ASTM grain size 10-12, noted on samples produced at less than 2500 J/cm^2 would be very useful in monolithic metallic materials due to the fact that it would behave superplastically[19]. This would allow SLS of parts allowing for a variety of uses or additional manufacturing techniques to be incorporated. This type of microstructure coupled with a post-process heat treatment would potentially enable production of equiaxed grain parts as opposed to the dendritic microstructure achieved from castings, thus providing more uniform and improved mechanical properties[19,20,21].

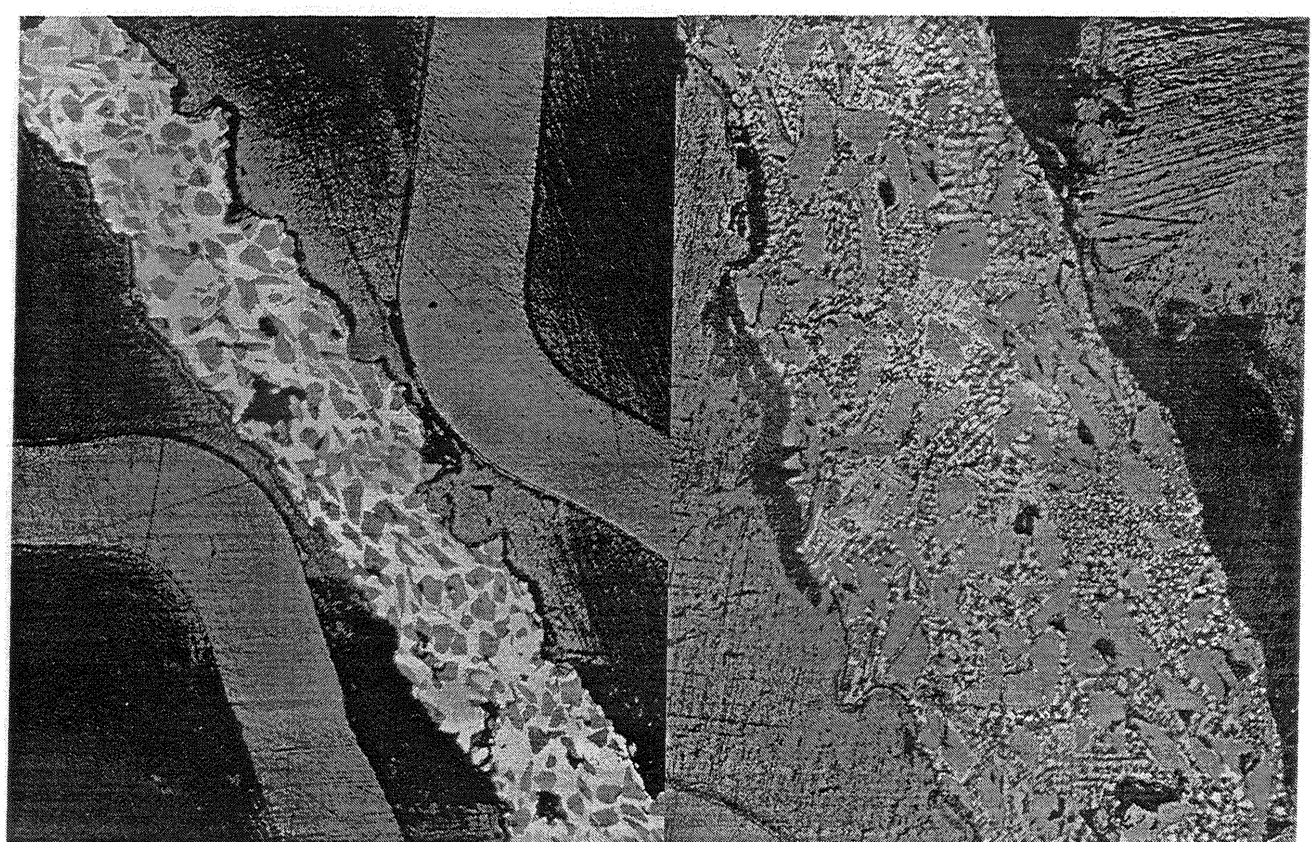

Figure 11. A sample produced at 2088 J/cm^2 energy density illustrating good microstructure, magnification 20 X and 50X. The 50 X photomicrograph of the etched sample illustrates a primarily dendritic microstructure with minimal entrapped porosity. The majority of the entrapped porosity is located at the boundary of a small equiaxed fine grain area.

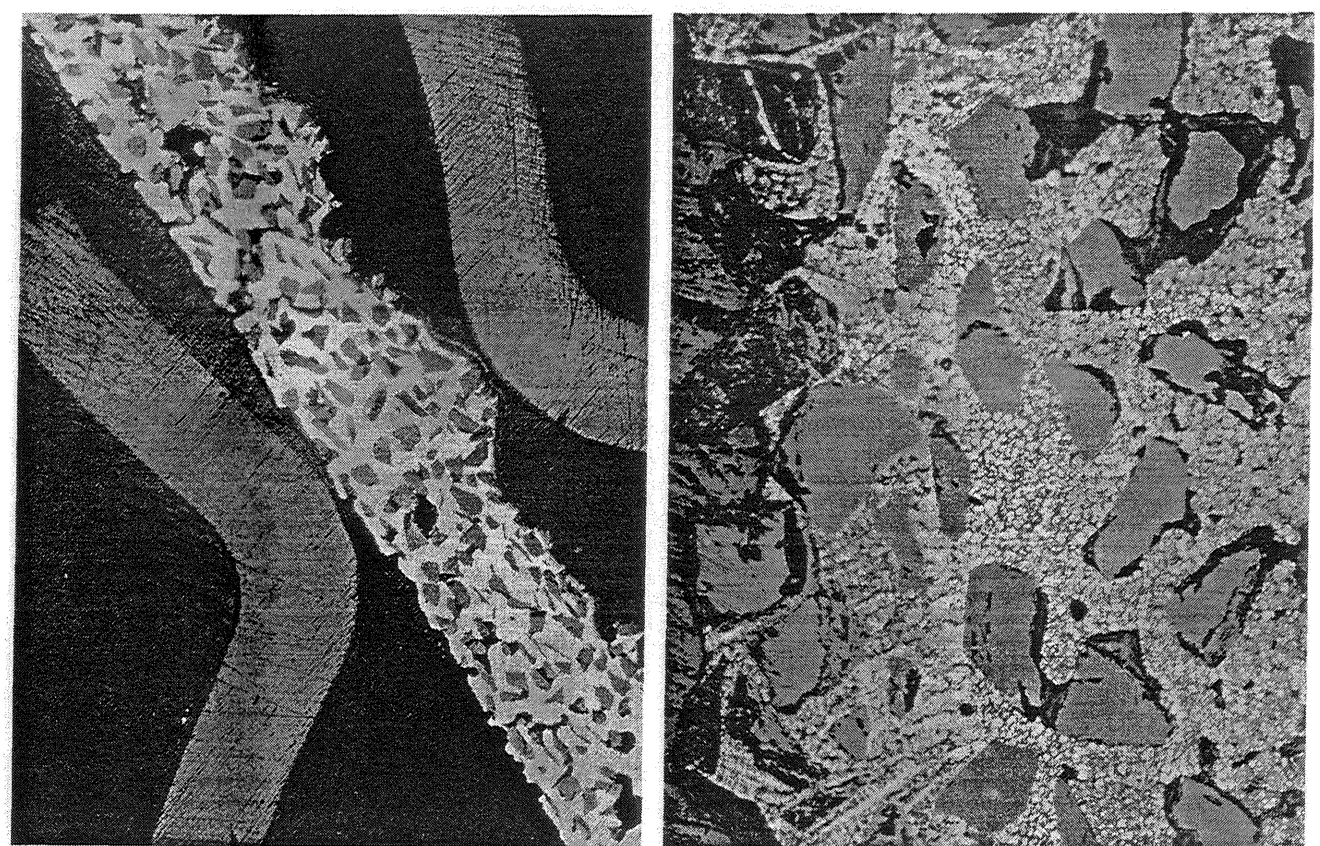

Figure 12. A sample produced at 1485 J/cm^2 energy density illustrating entrapped porosity around the grit particles, magnification 20 X and 100X. The 100 X photomicrographs illustrate the entrapped porosity and the fine equiaxed grain microstructure that result from the low energy density.

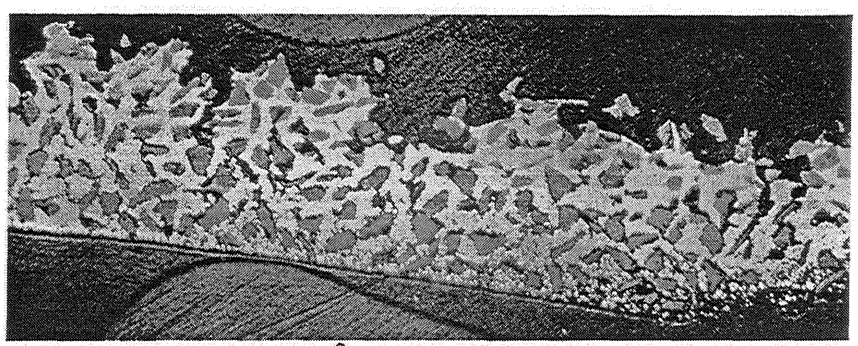

Figure 13. A sample produced at 1277 J/cm^2 energy density illustrating incomplete through thickness melting and entrapped porosity around the grit particles, magnification 20 X.

Process Parameters for Characterization

From the experiments described above a window of parameters that produced acceptable microstructures was available for mechanical property characterization. The energy density chosen for mechanical property characterization was 3202 J/cm^2.

Coupons were manufactured for rub testing and stress rupture testing. The mechanical testing specimens were fabricated and tested according to procedures described previously in the Indirect SLS section. The results are shown in Table 6.

Sample	Stress (psi)	Time (hrs)	Temperature (°F)
K442	500	50	2100 No Failure
L240	500	50	2100/15 hrs Braze failure
C274	500	50	2100 No Failure
N444	500	50	2100 No Failure

Table 6. Stress rupture test results of direct SLS processed cermet

Rub coupons were also manufactured from the samples and rub tested at room temperature. The results are provided in Table 7.

Processing	Composition	Volumetric Rub Ratio	Linear Rub Ratio
7/4 - A	SLS Brazeless	161	31
7/4 -B	SLS Brazeless	168	23
Allison Conventional	Brazeless	187	37

Table 7. Rub testing of direct processed cermet against seal material (Quantabrad 2)

These results indicate that the brazeless cermet material composition processed by direct SLS is equivalent to the standard cermet. For sample L240, the failure occurred at the braze joint, indicating a bond defect. Additional testing is required to establish improvement in performance attained by elimination of the braze constituent.

CONCLUSIONS

Direct SLS of cermet abrasive composites and monolithic metallic materials have been developed under this program. The processing parameters developed can be modified such that SLS of a variety of fully dense monolithic metallic materials can be conducted. The parameters for SLS of monolithic materials are adjustable such that the resulting microstructure can be tailored to a specific need. Energy densities of approximately 2000 to 4000 J/cm^2 are required to eliminate porosity retained around grit particles in the superalloy cermet composite. For this particular composite material the energy density should be such that the microstructure produced is just barely transformed to fully dendritic. Energy densities in the range 2500-3500 J/cm^2 will produce a fully dendritic microstructure. Energy densities of 1900 to 2200 J/cm^2 will produce a very fine grained equiaxed fully dense superalloy microstructure which may exhibit superplastic properties at elevated temperatures.

The mechanical testing results indicate that direct SLS can produce microstructure and properties equivalent to or better than the conventional labor intensive process.

The production of a small lot of abrasive cermet components and the recycling of all fall off material have proven that the process is production ready and dramatically reduces production costs as outlined in the cost analysis.

Compared to the conventional processing method, direct SLS offers the following benefits:
1. Reduced labor and variability by eliminating tape casting and rolling.
2. Repeatable production process.
3. Binderless process.
4. Elimination of lower melting point braze constituent from the composition.
5. Recyclable fall off material, minimal scrap from any lot size.

Indirect SLS offers the following benefits:
1. Reduced labor and variability by eliminating tape casting and rolling.
2. Repeatable production process.
3. Reduced labor in obtaining the correct thickness and porosity.
4. Ability to manufacture much smaller lot size as compared to conventional manufacturing method.

The indirect SLS process has some disadvantages as compared to the direct SLS process. These are:
1. Fall off material may possibly not be recyclable.
2. Requires handling the parts in the delicate green state which may produce additional scrap.

The next stage of research under this program will focus on developing a high yield, repeatable production process.

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