IMPROVEMENT OF WEAR COMPONENT'S PERFORMANCE BY UTILIZING ADVANCED MATERIALS AND NEW MANUFACTURING TECHNOLOGIES: CASTCON PROCESS FOR MINING APPLICATIONS

Quarterly Technical Progress Report

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ABSTRACT

FM Material was HIPped at 1200°C under 30 ksi. Full density was achieved. This material presents average Vicker's hardness of 1068 and fracture toughness of 10.05 MPa m^{1/2} in the fiber parallel direction and average Vicker's hardness of 987 and fracture toughness of 9.52 MPa m^{1/2} in the fiber perpendicular direction. Binder burnout of larger FM specimen (0.865" in diameter and 1.25" in length) was found very difficult. Large cracks and delamination appeared on the specimen's surface and interior even with a very slow burnout rate of 0.1°C/min was used.

EXECUTIVE SUMMARY

The last report identified the need to increase HIPping temperature of FM material over 1100°C and improve the binder burnout procedure. In this reporting period, the appropriate HIPping temperature required for consolidating the FM material to fully dense was determined. The mechanical properties of the FM material were tested. More burnout procedures have been tried in conjunction with ACR's thermal gravity analysis (TGA) on this material. However, severe cracking and delaminating still resulted, especially to larger FM specimens. The major task that will be addressed in the next reporting period is to investigate reasons for the cracking and delamination and to evaluate the solutions.

EXPERIMENT

HIPping

The temperature used by previous HIPping experiments has proven to be too low. The objective was to determine the appropriate HIPping temperature required to consolidate the FM material. Specimens were prepared by slicing a green rod of Batch 2 FM material, which was produced by ACR. One specimen (ACR-B2-HIP-1) was 0.25" thick and 0.865" in diameter, and another one (ACR-B2-HIP-2) was 1.25" tall and 0.865" in diameter. The smaller specimen was heated slowly in a vacuum furnace to burnout the binder material and then heated continuously to an elevated temperature for sintering. The burnout and sintering profile is given below:

25-500°C:	0.5°C/min
500°C:	30 minutes
500-1100°C:	5°C/min
1100°C:	60 minutes

After sintering, the specimen was inserted into a steel container and surrounded with sand. The container was covered using a steel lid with a steel stem in the center. The container was heated, vacuumed through the stem, sealed, and shipped to ACR. The HIPping was conducted at ACR in a mini HIP using the following procedure:

- Pressurize the vessel to 10 ksi; and
- Heat the specimen to 1200°C;
- Hold the temperature and pressure at 1200°C for 1 hr;
- Pressurize the vessel to 30 ksi;
- Hold the temperature at 1200°C and pressure at 30 ksi for 30 minutes;
- Allow to cool.

After HIPping, the container was returned to Michigan Tech, cut and opened. The specimen was checked for cracking, porosity, dimension change, microstructure, Vicker's hardness, and fracture toughness. The results showed reasonably good mechanical properties.

The larger specimen was then processed in the same way as the smaller specimen using the identical burnout, sintering and HIPping parameters. After HIPping, the larger specimen was checked for appearance, dimension change and open porosity.

Binder Burnout

Pimples, cracks, delaminating and bloating appeared in the larger specimen after sintering. To investigate the problems, several specimens of 1.25" in height and 0.865" in diameter, were heated in a vacuum furnace using very slow burnout rates as described below:

Procedure #1:

1. 0.5°C/min to 500°C burnout, 5°C/min to 1100°C sintering

Procedure #2:

1. 0.1 degree per minute to 200°C
2. One hour soak at 200°
3. 0.5 degree per minute from 200 to 300°C
4. 0.1 degree per minute from 300 to 400°C
5. 0.5 degree per minute from 400 to 500°C
6. One hour soak at 500°C
7. 5 degree per minute from 500 to 1100°C
8. One hour soak at 1100°C

RESULTS AND DISCUSSION

Smaller HIP specimen

Table 1 shows the results of examination on shrinkage and porosity. This specimen reached fully dense. (Figures 1 to 4 show its appearance. Figures 5 to 13 present its microstructure with the notation: nor = normal to extrusion. The axis, par = parallel to extrusion axis, 100m = 100X magnification, and vh = Vicker's hardness.) No remaining porosity was observed. These results indicated that the HIPping temperature and pressure (1200°C and 30 ksi) were appropriate. Table 2 gives the Vicker's hardness and fracture toughness test results. To compare with commercial WC insert's properties, a commercial 90% WC+10% Co insert was examined. Tables 3 shows its hardness and fracture toughness. In comparison with the mechanical properties of commercial WC material, the FM WC material shows better fracture toughness but lower hardness.

Larger HIP Specimen

Serious cracking, delamination and bloating occurred on this specimen. Figures 14 to 16 show the views of the specimen after binder burnout and sintering. Although cracking, delaminating and bloating also can be seen in the smaller specimen, the defects in the larger specimen were much more profound. Container HIPping should be able to close internal voids such as cracking and delaminating, but is not effective to close surface cracks. It is necessary to solve the burnout problem to make the FM material useful.

Binder Burnout

It was anticipated that the cracking, delaminating and bloating were caused by escape of vapor during burnout of the polymer binder in the FM green material. A Slower heating to lower the vapor evaporation rate in an attempt to reduce the cracking, delamination and bloating effects. Figure 17 shows the results of a slow burnout and sintering. There was no significant improvement. ACR also conducted parallel burnout experiments in a vacuum environment.

ACR Experiment #1:

Heating rate: 1°C/min

Soak Temperature: 200°C

Soak Time: 6 hrs.

Observations (Figs. 18 to 20): Excessive cracking, delamination between fibers, obvious bloating in the radial and along the height, as well as, “pimples” on the surface. Most distinctive cracks measured 0.7087 in. and 0.0394 in. wide. Most of the damage occurring in binder burnout is occurring below 200°C.

ACR Experiment #2:

Heating Rate: 1°C/min

Soak Temperature: 150°C

Soak Time: 6 hrs.

Observations: Cracking and delamination between fibers not as pronounced as previous, bloating in the radial and along the height. The most distinctive cracks measured 0.1969 in. and 0.0197 in. wide.

ACR Experiment #3:

Heating Rate: 1.25°C/min

Heating Rate: 0.1042°C/min

Soak Temperature: 150°C

Soak Time: 6 hrs.

Observations (Figs 21 to 23): Very much improved. Few thin delaminations. Very small crack between fiber bundles. Cracks are thin but still quite long. The most distinctive cracks measured 0.1969 in. and 0.0197 in. wide.

In ACR's experiments, cracking and delaminating started below 200°C. To determine the weight loss (evaporation rate) vs. temperature, a FM green material was sent to a lab to conduct a thermal gravity analysis (TGA), running at 170 torr with heating rate of 1°C/min. Figures 24 and 25 show the weight loss curves of the 94% WC + 6% Co material and the 94% WC + 6% Co (fiber) – Co (shell) FM material. The majority of weight loss took place in the temperature range from 350°C to 600°C. There was not much weight loss in the as expected in the temperature below 200°C according to the TGA curve. Therefore, vapor escaping was not the major reason to cause the burnout defects.

CONCLUSIONS

1. Combination of 1200°C and 30 ksi is appropriate to HIP the B2 FM material to fully dense.
2. The Vicker's hardness and fracture toughness of the B2 FM material in the extrusion direction are 1068 and 10.05 MPa m^{1/2} in the direction normal to the extrusion, respectively.
3. Cracking, delaminating and bloating are common and serious defects in larger FM specimens after binder burnout and sintering.

Tables and Figures

Table 1. Shrinkage and porosity.

Specimen	Processing	Initial Thick In.	Initial Dia. In.	Final Thick In.	Final Dia. In.	Thick Shrink %	Diameter Shrink %	Dry Weight g	Impregnated. Weight g	Saturated Weight g	Wire Weight g	Approx. Porosity %
ACR-B2-HIP-1 (ACR-B2-SIN-5)	25-500°C: 0.5°C/min 500°C: 30 min. 500-1100°C: 5°C/min 1100°C: 60 minutes HIPped at 1200°C & 30 ksi	0.242	0.802	0.188	0.772	22.31	3.74	17.4827	16.5132	17.4828	0.3212	0.01
ACR-B2-HIP-2 (ACR-B2-SIN-6)	25-500°C: 0.5°C/min 500°C: 30 min. 500-1100°C: 5°C/min 1100°C: 60 minutes HIPped at 1200°C & 30 ksi	1.162	0.822	1.003	0.726	13.68	11.68	87.7304	81.5160	87.7304	0.2619	0

Table 2. Hardness and fracture toughness.							
Sample	Acr_b2_hip_1						
Date	March 18, 2002	P=load, N=newton	50kg	490.5N		E=	588.48 GPa
	Vicker's Hardness (Hv)	Direction	Index 50X	Crack 1 200X	Crack 2 200X	C _o (m)	Fracture Toughness $K=0.016 (P/C_o^{3/2}) * (E/Hv)^{1/2}$ (MPa) m ^{1/2}
Normal							
1	1026	Horizontal	30	32	0	3.61905E-04	8.72
		Vertical	32	16	0	3.42857E-04	9.46
2	1093	Horizontal	31	0	0	2.95238E-04	11.47
		Vertical	30	0	0	2.85714E-04	12.43
3	1061	Horizontal	32	10	4	3.38095E-04	9.50
		Vertical	30	22	0	3.38095E-04	9.66
4	1063	Horizontal	29	17	0	3.16667E-04	10.47
		Vertical	29	41	23	4.28571E-04	6.77
5	1097	Horizontal	29	6	0	2.90476E-04	11.73
		Vertical	30	16	0	3.23810E-04	10.30
Normal Average	1068						10.05
Parallel							
1	987	Horizontal	30	41	0	3.83333E-04	8.16
		Vertical	31	0	0	2.95238E-04	11.84
2	1037	Horizontal	30	15	0	3.21429E-04	10.36
		Vertical	29	10	32	3.76193E-04	8.23
3	937	Horizontal	30	42	37	4.73810E-04	6.09
		Vertical	30	0	0	2.85714E-04	12.43
Parallel Average	987						9.52
Total Average	1027.5						9.78

Table 3. Hardness and fracture toughness.							
Sample	Superior Bit Insert						
Date	March 26, 2002	P=load, N=newton	50kg	490.5N		E=	654.00 GPA
	Vicker's Hardness (Hv)	Direction	Index 50X	Crack 1 200X	Crack 2 200X	C _o (m)	Fracture Toughness K=0.016 (P/C _o ^{3/2})*(E/Hv) ^{1/2} (MPa) m ^{1/2}
Normal							
1	1231	Horizontal	29	12	20	3.52381E-04	8.74
		Vertical	29	5	24	3.45238E-04	9.01
2	1226	Horizontal	29	12	19	3.50000E-04	8.84
		Vertical	29	20	10	3.47619E-04	8.92
3	1233	Horizontal	29	19	16	3.59524E-04	8.47
		Vertical	29	23	15	3.66667E-04	8.23
4	1237	Horizontal	29	15	29	3.80952E-04	7.75
		Vertical	29	15	19	3.57143E-04	8.56
5	1222	Horizontal	29	18	22	3.71429E-04	8.10
		Vertical	29	15	20	3.59524E-04	8.48
Normal Average	1229.8						8.51

Table 4. Dimension changes of specimens.			
Experiment #	Change in Weight, g	Change in Height, in.	Change in Diameter, in.
1	-0.4350, (-0.77%)	0.0105, (1.05%)	0.0190, (2.44%)
2	-0.2380, (-0.42%)	0.0025, (0.25%)	0.0295, (3.79%)
3	-0.2600, (-0.46%)	0.0010, (0.10%)	0.0082, (1.06%)

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure11

Figure 12

Figure 13

Figure 14

Figure 25

Figure 36

Figure 47

Figure 58

Figure 69

Figure 20

Figure 21

Figure22

Figure23

Figure 24

Figure 25