Improvement of Wear Component's Performance by Utilizing Advanced Materials and New Manufacturing Technologies: CastCon Process for Mining Applications

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Xiaodi Huang and Richard Gertsch

Michigan Technological University
1400 Townsend Drive
Houghton, MI 49931-1295

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Abstract

The microstructure and mechanical properties of a specimen HIPped at 1100°C under 60 ksi were examined. The examinations indicated that the proper HIPping temperature for this material should be higher than 1100°C. New recipe of monolithic material was developed and presented better extrusion homogeneity and less binder removal defects. However, cracking still occurred in specimens although very slow heating rate of 0.25°C/min for binder burnout was used.

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Experiment

During the last quarter, a fibrous monolithic material with a good combination of hardness and fracture toughness was successfully produced by hot pressing at 1150°C under 5 ksi. The sample shows the potential of better mechanical properties than the conventional WC/cobalt materials. Drill bit buttons made of this material will be produced either by pressureless sintering or hot isostatic pressing in a commercial production. Our industrial partner, ACR, prefers pressureless sintering because of lower production cost. However, the extrusion manufacturing and complex microstructure of the monolithic material may cause difficulty of consolidation. Hot isostatic pressing is an alternative route to overcome the difficulty but with a price of higher production cost.

The experiment conducted in this quarter aimed at 1) evaluating the mechanical properties of a HIPped sample, 2) improving extrusion process, and 3) refining binder removal and sintering process.

Microstructure and mechanical properties of HIPped specimen

The specimen (ACR-B1-HIP-1) HIPped at 1100°C under 60 ksi during the last quarter was cut into halves, one for the examination on the cross-section normal to the extrusion axis and one for the examination on the cross section parallel to the extrusion axis. The two resulting specimens were mounted, polished, tested using a Vicker's hardness tester and examined under a microscope.

Extrusion improvement

The microstructure of the first batch of fiber reinforced material was not homogeneous. ACR changed the recipe and optimized the extrusion procedure for the second batch. The second batch contained 94 wt% WC + 6 wt% cobalt in the cells and 17.5 vol% cobalt in the shells.

Binder removal and sintering

The binder in the fiber reinforced material needs to be removed by slow burning. The space left over by the binder need to be closed by sintering. Specimens after binder removal and sintering process conducted in the last quarter showed bubbles and cracks on surfaces and bodies. Several specimens were processed at lower heating rates and sintered at different temperatures in a vacuum furnace in this quarter to see if this problem can be solved.

Results and Discussion

Microstructure and mechanical properties of HIPped specimen

Figs 1 to 3 show the microstructure of the cross-section normal to the extrusion axis. The hexagonal WC/cobalt fibers are bundled by cobalt shells (Fig 1). The shells are very thin (Fig 2). Remaining pores can be seen in Figs 2 and 3, which mean that the HIPping temperature is not high enough to

close the pores. Figs 4 to 8 show the microstructure of the cross-section parallel to the extrusion axis. The cobalt lines (shells) are not parallel well (Figs 4). Some lines are much thicker in some regions and some lines are broken (Fig 6). Remaining pores also can be seen in Fig 8.

Figure 1. ACR-B1-HIP-1-N-a1

Figure 2. ACR-B1-HIP-1-N-a2

Figure 3. ACR-B1-HIP-1-N-a3

Figure 4. ACR-B1-HIP-1-P-a1

Figure 5. ACR-B1-HIP-1-P-b1

Figure 6. ACR-B1-HIP-1-P-c1

Figure 7. ACR-B1-HIP-1-P-d1

Figure 8. ACR-B1-HIP-1-P-e1

Table 1 gives the Vicker hardness test results. The hardness is lower than 1157 of the specimen produced by hot pressing. Microscope observation on the indents show that many cracks are generated near the tips of indents or along the cobalt line (Fig 9 to 15, 18 and 20). Higher load indentation produced irregular shapes of indents. It is obvious that some material underneath the indents are collapsed (Figs 16, 17 and 19), which indicates that pores may exist there. In comparison with the specimen produced by hot pressing, the hot pressed specimen has no cracks after indentation test but this HIPped specimen has many cracks. This means the HIPped specimen has much lower fracture toughness. All microstructure and mechanical test results tell that the specimen is not fully dense and porosity is the main reason to cause unsatisfied mechanical properties. To solve the problem, increasing HIPping temperature should be the first choice to close the remaining pores.

Table 1. ACR-B1-HIP-1 hardness test results (1100°C sintering + 1100°C HIPping)	
NORMAL TO EXTRUSION AXIS	Vicker Hardness
20 kg load	
1	1213
2	1013
3	1063
4	1135
5	977
Average	1080
50 kg load	
1	1062
2	831

Table 1. ACR-B1-HIP-1 hardness test results (1100°C sintering + 1100°C HIPping)	
NORMAL TO EXTRUSION AXIS	Vicker Hardness
3	1000
Average	964
PARALLEL TO EXTRUSION AXIS	
20 kg load	
1	1154
2	570
3	1134
4	1105
5	915
Average	976
50 kg load	
1	925
2	collapsed
3	collapsed

Figure 9. ACR-B1-HIP-1-N-ID-a1, 20 kg.

Figure 10. ACR-B1-HIP-1-N-ID-a2, 20 kg.

Figure 11. ACR-B1-HIP-1-N-ID-b1, 20 kg.

Figure 12. ACR-B1-HIP-1-N-ID-b2, 20 kg.

Figure 13. ACR-B1-HIP-1-N-ID-c1, 50 kg.

Figure 14. ACR-B1-HIP-1-N-ID-c1, 50 kg.

Figure 15. ACR-B1-HIP-1-N-ID-a1, 50 kg.

Figure 16. ACR-B1-HIP-1-P-IN-a1, 20 kg.

Figure 17. ACR-B1-HIP-1-N-ID-b1, 50 kg.

Figure 18. ACR-B1-HIP-1-N-ID-b1, 50 kg.

Figure 19. ACR-B1-HIP-1-N-ID-c1, 50 kg.

Figure 20. ACR-B1-HIP-1-N-ID-d1, 20 kg.

ACR: material prepared by ACR.

B1: batch one.

HIP: consolidation by HIP.

1: first HIP.

N: specimen cross section normal to the extrusion axis.

P: specimen cross section parallel to the extrusion axis

ID: after indentation.

a1: spot a, photo 1.

a2: spot a, photo 2.

Extrusion improvement

ACR designed a new recipe and produced a 0.865" in diameter and 4" long bar from the second batch of material. Cross-section examinations (Fig 21 and 22) show great improvement of extrusion homogeneity.

Figure 21. ACR-B2-SIN-1.

Figure 22. ACR-B2-SIN-2.

Binder removal and sintering

Table 2 gives the binder removal and sintering test results. Slowing heating rate did reduce cracking as seen in comparison of ACR-B2-SIN-1 with ACR-B2-SIN-2 in Fig 23. However, cracks still can be found even at very slow heating, 0.25°C/min as seen in Fig 24. High sintering temperature (1300°C) seemly produced relatively large channels as shown in Fig 25.

Table 2. Shrinkage and porosity

Specimen	Processing	Ini. Thick in	Ini. Dia. in	Fin. Thick in	Fin. Dia. in	Thick Shrink %	Dia. Shrink %	Dry Wt g	Impreg. Wt g	Satura. Wt g	Wire Wt g	App. Poros. %
ACR-B2-SIN-1	25-500°C: 1°C/min 500°C: 30 minutes 500-1100°C: 10°C/min 1100°C: 60 minutes	0.235	0.865	0.233	0.820	0.85	5.2	16.4664	15.3867	16.9680	.2617	27.22
ACR-B2-SIN-2	25-500°C: 0.5°C/min 500°C: 30 minutes 500-1100°C: 10°C/min 1100°C: 60 minutes	0.235	0.865	0.229	0.800	2.55	7.5	16.4682	15.2670	16.7835	.2617	17.73
ACR-B2-SIN-3	25-500°C: 0.5°C/min 500°C: 30 minutes 500-1300°C: 10°C/min 1300°C: 60 minutes	0.235	0.865	0.208	0.708	11.49	18.15	16.3180	15.3612	16.3781	.2617	4.70
ACR-B2-SIN-4	25-500°C: 0.25°C/min 500°C: 30 minutes 500-1250°C: 5°C/min 1250°C: 60 minutes	0.25	0.865	0.221	0.723	11.60	16.42	17.3701	16.3890	17.5005	.3216	9.10
ACR-B2-SIN-5	25-500°C: 0.5°C/min 500°C: 30 minutes 500-1100°C: 5°C/min 1100°C: 60 minutes	0.25	0.865	0.242	0.802	3.59	7.28	17.5668	16.5334	18.1313	.3216	29.41
ACR-B2-SIN-6	25-500°C: 0.5°C/min 500°C: 30 minutes 500-1100°C: 5°C/min 1100°C: 60 minutes	1.25	0.865	1.162	0.822	7.04	4.97	87.9490	81.3095	90.8000	.3216	29.06

Figure 23. ACR-B2-SIN-1 (left) and ACR-B2-SIN-2 (right).

Figure 24. ACR-B2-SIN-4.

Figure 25 ACR-B2-SIN-3.

Conclusion

HIPping temperature higher than 1100°C is required to achieve fully dense monolithic material. Heating rate slower than 0.25°C/min from 25°C to 500°C is not sufficient to prevent cracking. Extrusion homogeneity can be improved.