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

The project continued in this reporting period with focus on three issues: 1) failure analysis of the FM inserts tested in the field, 2) continued study of confinement burn-out, and 3) disc cutter manufacturing.

The failure analysis concludes that the main reason causing early failure of FM inserts is its low hardness, or in the other words, the FM inserts contained too much cobalt. The recipe to make the FM material needs to be changed.

The continued binder burn-out experiments showed that FM confinement burn-out in a metal container filled with sand is an effective way to remove the organic binder in the inserts without causing bloating and delamination.

Three 6.5" disc cutter sections were successfully produced. They were made of H13 powder with a green FM insert, a hot pressed FM insert, and a pre-sintered traditional WC insert respectively. One 17" disc cutter section was also produced from H13 powder with a pre-sintered traditional WC insert.

It is planned to test the heat treatment effect on the H13 and WC bonding and manufacture full 6.5" disc cutters in the next quarter.

Experimental

In the failure analysis of FM inserts, Hot Isostatic Pressing (HIPping) is used to produce inserts. The fibrous monolith (FM) is observed in macro and microstructure. Visual observations, rather than standardized techniques, were used to measure C-porosity in the FM inserts.

During the continued study of confinement burn-out, three FM inserts were tested. The three inserts were produced by cutting and machining a FM green rod which was made by ACM through a three pass extrusion. The first insert was embedded in a clay crucible filled with silica sand. The confinement came from the weight of top sand. The heating rate was 0.5°C/min from room temperature to 500°C, followed by a sintering to 1100°C for two hours. The second insert was embedded in a metal container fully filled with silica sand and covered by a metal lid. The confinement was introduced by the metal container's resistance to expansion. The burn-out rate was also 0.5°C/min from room temperature to 500°C, followed by sintering to 1100°C for two hours. The third insert burn-out and sintering was the same as the second one except much finer (100-150 mesh) graphite sand was used as the surrounding material. The third insert was then sintered to 1200°C for one hour. Then the third insert was sintered to higher temperatures in 50°C increments, then held at 1350°C for one hour. The insert was then sent to ACM for 1300°C and 30 ksi container-less HIPping.

Three 6.5" disc sections were produced with H13 powder using the CastCon process. The three sections contained a green FM insert, a hot-pressed FM insert, and a pre-sintered traditional

90% WC + 10% Co insert, respectively. The second insert was hot-pressed by ACM under 5 ksi at 1300°C. The third insert was pre-sintered in vacuum furnace at 1350°C for one hour.

Results and Discussion

This reporting period focused on three different issues: 1) failure analysis of the FM inserts tested in the field, 2) continued study of confinement burn-out, and 3) disc cutter manufacturing.

Failure Analysis of FM inserts

The field test conducted in the last reporting period showed that the FM inserts failed earlier than the traditional WC inserts in a pattern of premature wear. There was a thought that C-porosity existed in the FM material and was the major cause of the weak mechanical property. This thought was raised because the organic binder in the green FM may leave a great amount of carbon in the material after the organic binder is burned-out. ACM checked the microstructure of a finished insert.

The finished insert is WC (6%Co)-Co FM material HIPped under 30 ksi at 1200°C. With help from ACR, it was polished to reveal the FM macrostructure. Initial observations were: There is good extrusion and consistent macrostructure throughout the part. The part was consolidated well and of high density.

Upon polishing, the part was viewed under a microscope to see if residual carbon was present (Figure 1). Residual carbon is typically observed as black or dark spots. No significant amount of C-porosity was observed in the piece. In stating that, however, ACR does not have the ability to rate the amount of C-porosity present within the part as compared to the carbide industry. Each supplier of carbide standardizes a technique and reference from which a piece is quantified as being saturated by C-porosity, thus deemed unacceptable. However, the insert has less visible C-porosity than some of the sample inserts ACM has sectioned.

The bottom surface of the insert was etched to reveal eta phase (a darker orange color of Figure 2). Eta phase is the lack of carbon. Again, eta phasing is also considered a defect in the carbide industry. The figures attached are taken after etching. There is very little eta phase present in the carbide core. However, there is eta phase present throughout the cobalt interface. This makes sense since there should be little or no carbon in the pure cobalt interface.

It is ACM's opinion that although C-porosity may be present, they do not think it was a major contributing factor. ACR/ACM does not have a valid method for quantifying C-porosity and is basing its opinion on observation and comparison based on other FMs produced. It is also their opinion that the FM was of solid structural integrity, high density and regular FM structure. However, they think that the increased wear may be due to the soft and ductile nature of the cobalt interface. This material system may not be suitable for this application.

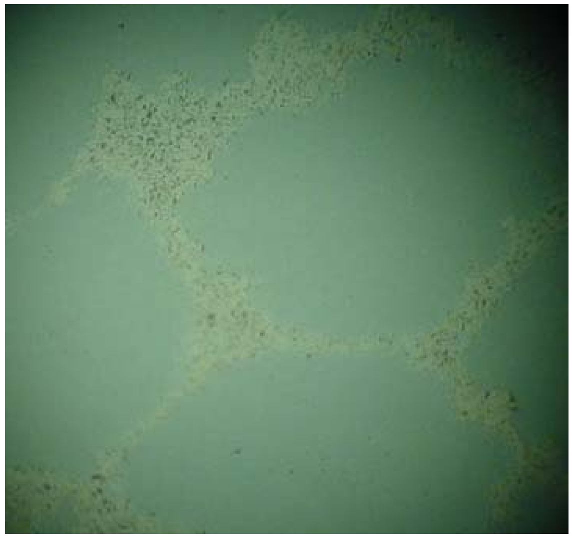

Figure 1. WC(6%Co)-Co FM after etching at 20X, 1st view.

Figure 2. WC(6%Co)-Co FM after etching at 20X, 2nd view.

Continued Study of Confinement Burn-Out

The experiments conducted in the sixth quarter concluded that confinement burn-out can solve the cracking and delamination problem. This success raised a hope of container-less HIPping. In container-less HIPping, the FM inserts after burn-out will be sintered to a relative density higher than 95%, or to the level that internal pores are isolated. The remaining pores will be closed by high temperature and high pressure gas acting on the external surfaces of inserts during HIPping. Because there is no metal container and seal required, the container-less HIPping will lower the manufacturing cost dramatically. In this quarter, experiments of confinement burn-out continued to find the optimum burn-out and sintering conditions for achieving relative density higher than 95%.

Three green FM inserts were tested. The first insert was embedded in a clay crucible filled with silica sand. The confinement came from the weight of top sand. Figures 3-6 show the appearance of the insert after burn-out and sintering. Bloating is obvious on the upper part of the insert, which suggests that confinement by sand weight is not sufficient.

The second insert was embedded in a metal container fully filled with silica sand and covered by a metal lid. The confinement was introduced by the metal container's resistance to expansion. Figures 7-9 show the appearance of the insert after burn-out and sintering. From these figures, we can see that FM material penetrated into the surrounding sand and there are many large internal pores. We think this is due to the coarse surrounding sand (20-28 mesh) giving little resistance to the penetration of FM material into the sand interspaces.

The third insert burn-out and sintering was the same as the second one except much finer (100-150 mesh) graphite sand was used as the surrounding material. Figures 10-12 show the appearance of the resulting insert. There were no cracks or bloating at all. However, a density measurement revealed that the insert was not fully dense. The insert absorbed water. The insert was then sintered to 1200°C for one hour and checked for its density after cooling. The insert still absorbed water. The insert was sintered to higher temperatures in every 50°C increment, until 1350°C for one hour. The insert absorbed no water, assuming over 95% relative density. The insert was then sent to ACM for 1300°C and 30 ksi container-less HIPping.

Disc Section Manufacture

Three 6.5" disc sections were produced with H13 powder using the CastCon process. The three sections contained a green FM insert, a hot-pressed FM insert, and a pre-sintered traditional 90% WC + 10% Co insert, respectively. Figure 13 shows the produced sections. There is a concern of potential cracking during quenching of the heat treatment required for H13 steel due to the great property differences between the H13 body and WC insert.

Conclusions

Failure analysis of the FM inserts indicates that there is too much cobalt in the mix, causing the inserts to be too soft. The ongoing binder removal experiments indicate that further work is needed to test container-less HIPping. Disc section manufacturing is just getting underway.

Future Work

It is planned to manufacture three full 6.5" disc cutters, continue container-less HIPping effort, and conduct a heat treatment test on one of the 6.5" disc section in the next quarter.

References

No references are included in this quarterly report.

Figures 3 – 6: Confinement burnout, Test 1. Insert was embedded in a clay crucible filled with silica sand. The confinement came from the weight of top sand. The heating rate was 0.5°C/min from room temperature to 500°C, followed by a sintering to 1100°C for two hours.

Figures 7 – 9: Confinement burnout, Test 2. Insert was embedded in a metal container fully filled with silica sand and covered by a metal lid. The confinement was introduced by the metal container's resistance to expansion. The heating rate was 0.5°C/min from room temperature to 500°C, followed by a sintering to 1100°C for two hours.

Figures 10 – 12: Confinement burnout, Test 3. Insert was embedded in a metal container fully filled with graphite sand and covered by a metal lid. The confinement was introduced by the metal container's resistance to expansion. The heating rate was 0.5°C/min from room temperature to 500°C, followed by a sintering to 1100°C for two hours. The insert was then sintered to 1200°C for one hour. Then the insert was sintered to higher temperatures in every 50°C increment, until 1350°C for one hour.

Figure 13. 6.5" disc sections