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Microstructural and Mechanical Characteristics of In Situ Synthesized Chromium-Nickel-Graphite Composites

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Abstract

Cr-C-Ni composites were synthesized in situ from elemental powders of Cr, Ni and C by high energy milling followed by reactive sintering. The milled powders with the grain size in nano-scale were pressed to compacts and sintered. During the following thermal treatment at first the chromium carbide was formed and then the Cr_3C_2-Ni cermets were sintered in one cycle. The interface between the binder phase and the carbide grains of the in situ composite has a good bonding strength as it is not contaminated with oxidation films or other detrimental surface reactions.

Keywords : In-situ composites, Chromium carbide, Reactive sintering, Erosion, Abrasive wear

1. Introduction

Cr_3C_2-Ni cermets are perspective materials to operate in environments being simultaneously corrosive and abrasive [1, 2]. Main disadvantages of these cermets are relatively low mechanical properties and wear resistance mainly because of their coarse-grained structure (the carbide grain size is usually over 4 μm). Active growth of carbide grains during sintering is characteristic to Cr_3C_2-Ni cermets. The finer is the powder, the higher is its interface energy and the faster the carbide grains tend to grow during sintering [3]. Sintering temperature and time are among the most important factors determing the structure and properties of Cr_3C_2-Ni cermets. As the reactive sintering has not been used for production of the Cr_3C_2-Ni cermets before, the influence of the technological variables (sintering temperature and time) on the structure and properties – erosion and abrasive wear resistance in particular – was studied.

2. Materials and experimental methods

Pure chromium (Cr), carbon black (C) and nickel (Ni) powders were used as starting materials. The milling experiments were performed in an attritor mill equipped with WC-Co alloy reinforced vial minimize contamination. Milled powder was compacted and sintered at 1250 °C (Cr_3C_2 – 20 and 30 wt.% Ni) and 1300 °C (Cr_3C_2 – 10 wt% Ni) during 60 min.

3. Results and discussion

The results of the current study have confirmed that even with a high amount of mechanical activation it is quite difficult to force the chromium and carbon to react at the room temperature. Most critical is the capability of the milling device to provide enough collision energy. The so-called mechanically activated synthesis (MAS) turned out to be much better approach. By this technique the starting materials are at first activated by high-energy milling at room temperature and then the synthesis reaction is completed at moderate temperature. Because of mechanical activation the reaction temperature is still much lower, compared with un-activated powder with the same composition. Furthermore, the synthesis reaction of Cr and C can be combined with the liquid phase sintering of Cr_3C_2-Ni cermets.

Powder particles after high-energy milling are in nanoscale (60-90 nm) with internal crystallites of 10-15 nm. During the high-energy milling, graphite is smeared onto Cr particles. Meanwhile, C atoms first segregate in the crystal interfaces of Cr, then diffuse gradually and during the heat-treatment react with Cr to form chromium carbide completely.

According to XRD analysis the synthesis reaction of Cr_3C_2 takes place at the temperatures between 600 and 900 °C, while no reaction between chromium and carbon was detected below 600 °C.

The reactive sintered Cr_3C_2 - Ni cermets have fine microstructure – the mean carbide grain size is about 3 μm. Microstructure of the cermets produced by conventional technology is less homogeneous and the mean carbide grain size is higher – about 5 μm.

In this study it was shown that the reactive sintering is practically applicable for manufacturing of the chromium carbide cermets. As seen from the table, the mechanical properties of the reactive-sintered cermets are found superior to alloys with the same composition, produced by traditional PM routine.

Table . Mechanical and tribological properties of Cr_3C_2-Ni cermets produced by different technique

Ni cont., mass %	Technique	Carbide grain size, μm	HV	TRS, MPa	Erosion rate, mm^3/kg	Wear coef., k x 10^{-4} mm^3/Nm
10	Conv.	5.4	1330	670	4.5	1.2
10	React.sint.	2.8	1410	990	3.0	1.0
20	Conv.	5.1	1180	1030	5.9	6.2
20	React.sint.	2.3	1270	1160	2.8	3.1
30	Conv.	4.9	820	990	9.8	11.5
30	React.sint	2.9	1020	1350	7.6	6.8

As seen from the table, the hardness and TRS of the Cr_3C_2-Ni cermets depends mainly on the binder content and only lightly on the production technique. The hardness and TRS of the reactive sintered cermets are 15-30% higher than that of the cermets fabricated by conventional technology. The erosion rate and abrasive wear coefficient also depends on the carbide-to-binder content and production method. The reactive sintered cermets are 1.2-2 times more wear resistant, compared with the conventional method (at the same chemical composition). This behaviour can be explained by smaller carbide grain size of the reactive sintered cermets and better strength between the carbide and the binder phase.

4. Conclusions

1. The reactive sintering enables to obtain uniform fine-grained Cr_3C_2-Ni cermets with high mechanical and tribological properties as well to decrease the production costs of the alloys.
2. The carbide grain growth during the reactive sintering is somewhat retarded as compared with the traditional process. As a result, the microstructure of the reactive sintered cermets is fine-grained, more homogeneous and less porous than that of the cermets, produced by conventional method.
3. The mechanical properties (hardness, transverse rupture strength), abrasive erosion and sliding wear resistance of the reactive sintered cermets are higher than that of the cermets produced by conventional method (at same chemical composition).

5. Acknowledgements

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6. References

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