Elaboration of (Steel/Cemented Carbide) Multimaterial by Powder Metallurgy

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Abstract

A steel/cemented carbide couple is selected to generate a tough/hard two layers material. Sintering temperature and composition are deduced from phase equilibria, and experimental studies are used to determine optimal conditions. Liquid migration from the hard layer to the tough one is observed. Microstructure evolution during sintering of the tough material (TEM, SEM, image analysis) evidences coupled mechanisms of pore reduction and WC dissolution. Liquid migration, as well as interface crack formation due to differential densification are limited by suitable temperature and time conditions.

Keywords : multimaterial, phase equilibria, sintering, porosity evolution, image analysis

1. Introduction

The present work aims to define a Powder Metallurgy route for two-layer parts made of tough steel and hard cemented carbides layers. The sintering treatment must generate dense layers with good interface. Experimental studies are performed to evidence and understand the involved mechanisms. The two material families to be associated have been selected with Granta's CES selector™ software, the criteria being mechanical properties (toughness and hardness) and melting temperature. Cemented tungsten carbides and steel have been selected as hard and tough materials respectively [1]. Compositions and sintering temperature are chosen to get Liquid Phase Sintering (LPS) [2] of the hard layer and Transient Liquid Phase Sintering (TLPS) of the tough layer. The compositions are deduced from phase diagrams of the Fe-W-C system [3]. The selected compositions are {12at% (Fe, 9at%C) – WC} and {Fe, 2at%W, 4.5at% C} for the hard and tough layers respectively. The chosen temperature range is 1180-1330°C, above the ternary eutectic Fe-WC-Fe_3C and below the maximum recommendanded value owing to WC solubility in Fe [2].

2. Experimental Procedure and First Experiments

The materials were prepared from 5.5µm WC (Sandvik), 5µm Fe (Eurotungstene Poudres). Graphite (Cg) excess is added to balance the C losses, calculated from the O content of the starting powders. For each layer, Fe, WC, and Cg powders were mixed for 60 min in a Turbula device. Cylindrical compacts (∅16 mm) were obtained by co-compaction of the two mixtures in a metal die (600 MPa).

First experiments showed that the ternary eutectic liquid phase formed during LPS of the hard layer, infiltrates the tough layer. This liquid migration forms large pores and originates a porosity gradient in the hard layer.

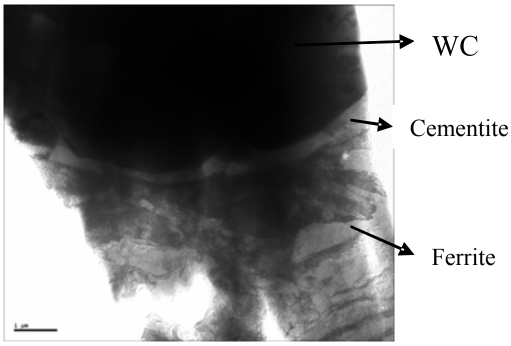

Fig. 1. TEM image showing the constitution of the sintered Fe base material.

3. Sintering of the Fe base material

A preliminary study of the sintering of Fe base material was performed by T.E.M. on samples sintered for 2 and 120 minutes at 1300°C. Diffraction patterns indicate the presence of ferrite and cementite. Observations reveal a lamellar type structure of cementite in the matrix of ferrite next to the WC grains (Fig.1), consistent with phase equilibria data [4]. SEM observations (Fig.2) and image analysis (Fig. 3) show that porosity and WC fractions decrease when sintering temperature is increased.

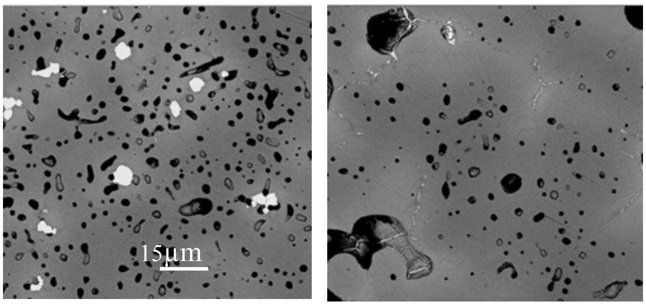

Fig. 2. SEM micrographs of the samples sintered at 1298 and 1324°C during 2 minutes

Sintering experiments for 2min were performed. For sintering temperatures between 1260 and 1315°C, porosity is mainly fine and rounded, with few elongated pores (Fig. 2). At higher temperature (1324°C) coarse and irregular shape pores appear (Fig. 2), higher than in size than the WC grains and the rounded pores, while most of the WC grains have disappeared.

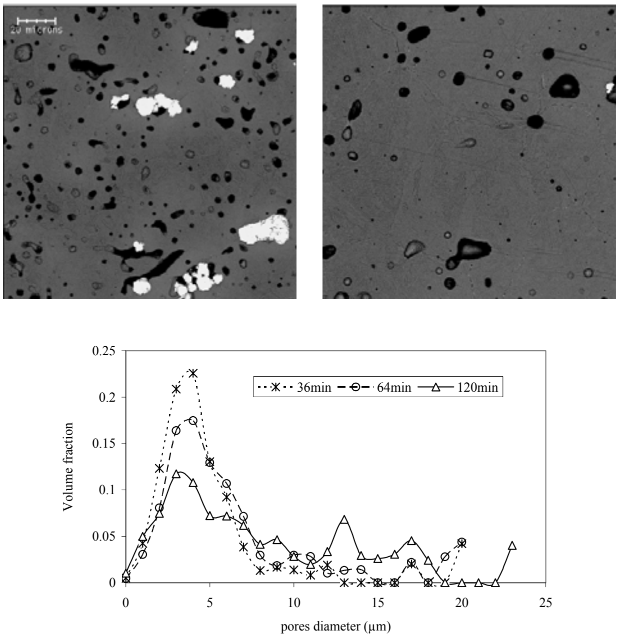

Fig. 3 Sintering at 1300°C micrographs at 16 and 120 minutes and distributions of pores diameter for Fe base samples sintered at 1300°C for 36, 64 and 120 minutes.

Systematic observation of carbide at the grain boundaries in the vicinity of dissolving carbides suggests that WC dissolution occurs by the formation of a liquid phase. This transient (local inhomogeneous composition) or a permanent liquid (at higher temperature) appears around the WC grains and infiltrates along the grain boundaries. At higher temperatures (1324°C), the formation of a permanent liquid can explain the complete dissolution of WC and formation of coarse pores even for very short times.

This undesirable large pore formation above 1320°C at high temperature and the limited pore elimination at lower temperatures leads to reduce the optimal temperature range to 1300-1315°C. Sintering experiments at 1300°C for 2 to 120 minutes have been performed. Observation as well as image analysis measurements (Fig.3) confirm the above mentionned tendencies and mechanisms of associated WC dissolution and pore evolution. Large pores from WC dissolution become significant after 40 min (Fig.3).

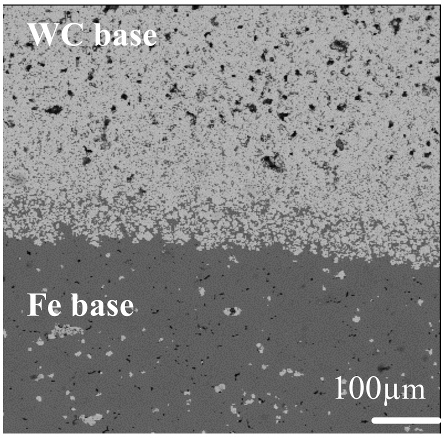

Fig. 4. Microstructure at the interface of the {Fe, 2at%W, 4.5%C}/{12%(Fe, 9%C)-WC} couple sintered at 1280°C.

4. Sintering of Two Layer Materials

In order to limit liquid infiltration from the WC base layer to the Fe base layer, the thermal cycle was carried out in two steps: the first one (60 min at 1080°C) produces a significant densification by solid state sintering of the Fe base part which prevents later infiltration ; the second step (10 min at 1300°C) induces the rapid shrinkage of the WC rich part by LPS sintering. Another difficulty is the crack formation at the interface between the tough Fe base layer and the hard WC base layer. The use of a lower temperature (1280°C) has lead to a two layer material with good cohesion, without significant liquid infiltration (Fig 4), and with suitable mechanical properties (183±6 HV and 900±70 HV for the tough and hard layers respectively).

5. References

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