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JOURNAL DE PHYSIQUE
Colloque C10, supplément au n°12, Tome 46, décembre 1985 page C10-387

# INTERNAL FRICTION SPECTRUM OF WC-Co COMPOSITE ALLOYS

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Résumé - Des mesures de frottement intérieur ont été réalisées sur divers carbures frittés à base de WC-Co. Ces matériaux présentent un spectre caractéristique composé principalement d'un pic apparaissant dans un domaine de température où la plasticité de la phase Co commence à jouer un rôle non négligeable sur les propriétés mécaniques.

Abstract - Internal friction measurements have been performed on diverse types of WC-Co sintered carbides. These materials exhibit a characteristic internal friction spectrum which is mainly composed of a peak located in a temperature range where the plasticity of the Co phase starts to play a sensitive role on the mechanical properties.

## I. INTRODUCTION

The WC-Co composite alloys are sintered carbides which exhibit remarkable mechanical properties [1] (high values of hardness and elastic modulus, good wear resistance), and are consequently well suited for cutting tools. During machining, the cutting tools are effectively subjected to strong mechanical and chemical solicitations, which limit their "life time". In order to increase this "life time", many semi-empirical developments, based for instance on the additions of alloying elements, have led to the commercialization of diverse types of WC-Co based hardmetals [2]. From the tests of such materials it appears that toughness play an important role on the "life time" of the tools [3]. It is then important to have a better understanding of the fundamental mechanisms, which are responsible for the mechanical properties, more precisely the toughness, of these materials.

The aim of the present research is to study these mechanisms by means of internal friction measurements. Internal friction is a technique well suited to the study of the microplastic phenomena which take place in the hard and brittle materials. Effectively the range of amplitudes investigated by internal friction measurements corresponds well to the domain of plastic deformation which is reasonable for using such materials.

In the present paper, the internal friction spectrum of WC-Co is presented and used to put in evidence the primordial role played by the cobalt binder phase in the mechanical behaviour of hardmetals.

## II. EXPERIMENTAL DATA

Specimens of WC-Co (5, 11 and 23 wt%Co) have been sintered under the shape of bars of 110 x 20 x 2.5 $mm^3$ by STELLRAM S.A., Nyon, Switzerland. From these bars, sheets of 0.2 x 2.5 x 110 $mm^3$ have been cut by electroerosion, and mounted in a classical torsional pendulum. The measurements have been performed at low frequency from room temperature up to 1000 °C under vacuum (~ $10^{-5}$ Torrs). Internal friction is deduced from the wave form analysis of the free decay signal [4].

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## III. RESULTS

WC-Co hardmetals exhibit a characteristic internal friction spectrum. Figure 1 shows a result obtained in WC-11%Co. From room temperature up to 600 K, the internal friction is weak and constant. From 600 K, it increases exponentially with the temperature and the level of damping can be rather high ($10^{-2}$) at ~ 1000 K. Superimposed to this exponential increase, one can observe an internal friction peak at ~ 800 K (for a frequency of ~ 0.6 Hz). This peak is a relaxation peak, because it shifts in temperature when the frequency is changed. The deduced activation energy is ~ 2.7 eV and the broadening factor ~ 2.5.

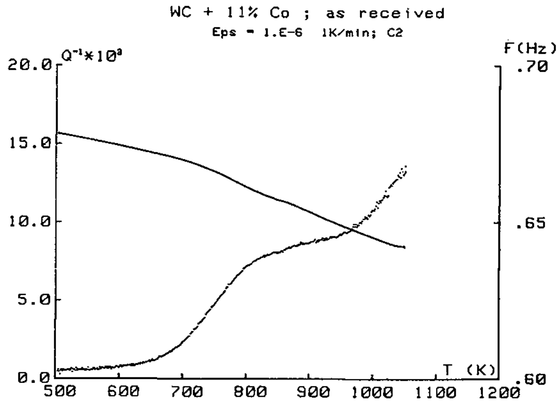


Fig. 1 : Internal friction and oscillations frequency of a WC-11%Co specimen as a function of the temperature.

Measurements have also been performed on specimens which contain 5 wt% and 23 wt%Co. The results are compared to the precedent one on figure 2. The internal friction, peak and exponential background, increases with the Co concentration. In addition, the relaxation peak shifts towards lower temperatures.

These results tend to show that the internal friction of WC-Co is associated with mechanisms which take place in the Co binder phase. This idea is still supported by the results obtained in WC-Co hardmetals, which have been doped with alloying

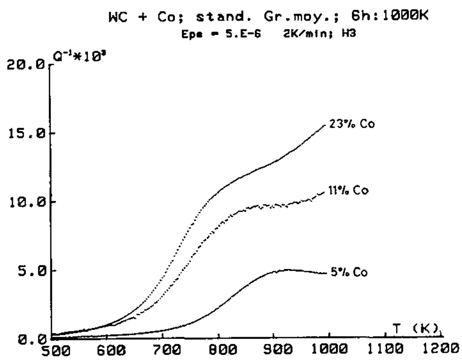


Fig. 2 : Effects of the Co content on the internal friction of WC-Co.

elements as Cr or Ru (Fig. 3). It is known [2] that Cr and Ru change the properties of the Co binder phase of WC-Co. On the other hand, they play an important role on the limitation of the grain growth during sintering.

With respect to the internal friction of pure WC-11%Co, the additions of Ru or Cr shift the curves towards higher temperatures. Moreover, in the case of WC-11%Co with additions of Cr, the internal friction is lower.

The three curves of figure 3, have been obtained after the same thermal treatment: 12 hours annealing at 1000 K. But, in the case of the hardmetal doped with Cr, a great evolution of the internal friction has been observed during annealing (fig. 4). At the first run in temperature, the internal friction peak is rather high. During annealings at 1000 K, the peak and the internal friction background decrease. Simultaneously, one can observe an increase of the frequency or of the elastic modulus. This behaviour can give an account for an evolution of the microstructure which was not at the equilibrium after sintering.

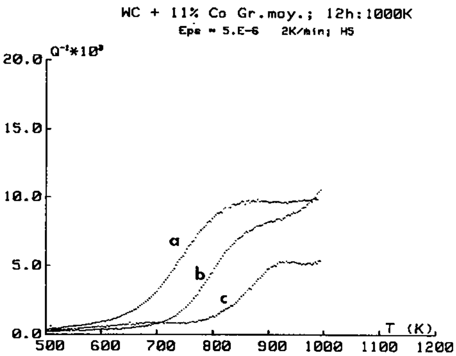


Fig. 3 : Internal friction spectrum of
a) WC-11%Co
b) WC-11%Co + Ru
c) WC-11%Co + Cr

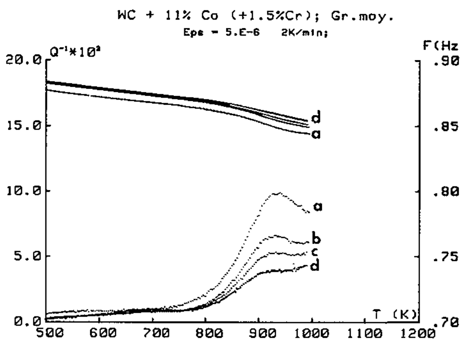


Fig. 4 : Effects of annealings at 1000 K on the internal friction of WC-11%Co - 1.5%Cr.
a) as received
b) annealed 6 hrs at 1000 K
c) annealed 12 hrs at 1000 K
d) annealed 24 hrs at 1000 K

## IV. DISCUSSION

The internal friction peak observed at low frequency in WC-Co is located in the same temperature range than the increase of the critical stress intensity factor $K_{IC}$ measured by H. Si Mohand and G. Fantozzi [5, 6]. These authors have interpreted their results as following. From room temperature up to 600 °C, the material is brittle and fracture is due to the propagation of cracks from critical defects. In this temperature range, $K_{IC}$ is then constant. From 600 °C to 800 °C, the material present some plasticity due to an increase of ductibility of the Co phase. An increase of $K_{IC}$ is then observed.

The measurements of Si Mohand and Fantozzi have been performed in WC-6%Co. By the comparison of their results with the internal friction of WC-5%Co (fig. 2), one remarks that the critical temperature of 600 °C (873 K) is the temperature of the peak. Then, by taking into account the above interpretation, it is possible to conclude that the peak is certainly associated with a kind of "brittle-ductile" transition of the material.

Now, the appearance of plasticity in the binder phase can certainly be due to an increase of the dislocations mobility.

In the Co phase, many foreign atoms are in solution, which are susceptible to interact with the dislocations, giving rise to pinning, depinning, or dragging phenomena. As a matter of fact, the diffusion energy of W in Co is 2.95 eV/at [7]. This value is very close by the activation energy (~ 2.7 eV) of the internal friction peak. It is then possible to assume that the peak is due to a mechanism of interaction between dislocations and solute atoms in the Co phase. In such a model, the internal friction depends on the dislocation loops length and on the concentration of solute atoms. The dislocation loops length can act on the height and the position in temperature of the peak. On figure 2, smaller loops lengths in WC-5%Co give rise to a smaller peak located at higher temperature than in WC-11%Co. The reduction of the dislocation loops length can be due to the decrease of the mean free path of the Co phase with the Co content. On the other hand, the decrease of the peak during annealing of WC-11%Co with additions of Cr (fig. 4) can be due to the decrease of the concentration of solute atoms by a precipitation process.

In any case, the internal friction increase in the temperature range of the peak is certainly, associated with the mechanical properties of the materials. For instance, the addition of Ru to WC-Co, which increases the transverse rupture strength [2], gives rise to a shift of the curves towards higher temperatures. Naturally, it must be still precised if these effects are due to a grain refinement process or to the hardening of the Co phase. As a matter of fact, the mechanical properties of the binder phase are of prime importance in many theoretical considerations of the rupture mechanics [8].

## V. CONCLUSIONS

WC-Co composite alloys exhibit a characteristic internal friction spectrum mainly composed of a relaxation peak superimposed to an exponential increase of the background. The peak is located in the same temperature range than the increase of toughness observed by other authors [5, 6], and attributed to the increase of ductility of the Co binder phase. Internal friction seems then to be a technique well suited to the study of the microscopic mechanisms which are responsible for the microplasticity of hardmetals.

## ACKNOWLEDGMENTS

This work is supported by the Swiss "Commission pour l'Encouragement de la Recherche Scientifique". The authors are also grateful to Dr. Woirgard and Dr. Mazot, ENSMA-Poitiers, for measurements in low frequency range which have been very precious for determining the activation energy.

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