Ceramics International 42 (2016) 12701–12708

Contents lists available at ScienceDirect

Ceramics International

journal homepage: www.elsevier.com/locate/ceramint

Influence of the microstructure on the thermal shock behavior of cemented carbides

Jose Maria Tarragó [a,b,1], Selassie Dorvlo [c], Joan Esteve [d], Luis Llanes [a,b,*]

[a] CIEFMA, Departament de Ciència dels Materials i Enginyeria Metal•lúrgica, ETSEIB, Universitat Politècnica de Catalunya, Barcelona 08028, Spain
[b] CRnE, Centre de Recerca en Nanoenginyeria, Universitat Politècnica de Catalunya, Barcelona 08028, Spain
[c] Sandvik Hyperion, Coventry CV4 0XG, UK
[d] Departament de Física Aplicada i Óptica, Universitat de Barcelona, Barcelona 08028, Spain

ARTICLE INFO

Article history:
Received 14 April 2016
Received in revised form
29 April 2016
Accepted 5 May 2016
Available online 6 May 2016

Keywords:
Cemented carbides
Thermal shock
Hasselman parameters
Fractography
Strength degradation

ABSTRACT

The influence of single and repetitive sudden changes of temperature on the mechanical integrity of cemented carbides was investigated as a function of their microstructure. Thermal shock resistance was assessed by testing the residual flexural strength of hardmetal beams after being subjected to thermal shock by water quenching. Results indicate that hard cemented carbides tend to exhibit a superior resistance to the nucleation of thermal shock damage but a lower resistance to the propagation of this damage mechanism than tough grades, and vice versa. These trends are in agreement with those expected from the evaluation of the thermal shock Hasselman's parameters. The evidenced strength loss after thermal shock may be related to the subcritical growth of intrinsic flaws driven by localized microcracking surrounding them. Results also point out on Ni-base hardmetals to exhibit a slightly higher resistance to abrupt changes of temperature than Co-base ones.

© 2016 Elsevier Ltd and Techna Group S.r.l. All rights reserved.

1. Introduction

Cemented carbides, usually referred to as hardmetals, are composite materials consisting of hard ceramic particles embedded in a tough metallic matrix acting as a binder. They exhibit an exceptional combination of strength, toughness and wear resistance as a result of the extremely different properties of their two constitutive phases [1]. These merits endow hardmetals as first choice materials for a wide range of severe applications, including exposure to harsh service conditions such as corrosive environments, high temperatures, or abrupt temperature changes [2]. Nevertheless, despite its exceptional thermal conductivity and excellent fracture toughness in comparison with ceramic materials, WC–Co cemented carbides are sensitive to thermal shock due to its brittle-like nature behavior [3,4]. Thus, thermal cracking and thermal fatigue are recognized as common modes of failure of cemented carbide tools in different applications, such as in intermittent cutting and rock drilling [5–9]. However, different from the case where pure mechanical loads are implied [9,10], studies devoted to thermal shock resistance of hardmetals are relatively scarce [3,4,11–15]. Further, these studies only relate to Co-base hardmetals, and the influence of the microstructure on the strength degradation of these materials due to thermal shock is hardly addressed. Therefore, in this paper the influence of three different microstructural variables on the thermal shock resistance of cemented carbides are evaluated and discussed. These include: binder chemical nature, binder content, and carbide mean grain size. Within this context, it is worthy to remark that the replacement of Co metal by alternative binders is one of the major challenges of hardmetals community [16]. That is particularly important nowadays, due to the classification of cobalt dust as a toxic and carcinogenic material by both, the European program for Registration, Evaluation, Authorisation and Restriction of Chemical substances (REACH) and the U. S. National Toxicology Program (NTP).

The measurement of the retained strength after a quench test is a common method for evaluating thermal shock resistance of ceramics. The test consists in determining the critical thermal shock temperature difference (ΔT_c) above which the residual strength is reduced up to values of 70% the average strength measured at room temperature [17]. Aiming to rationalize thermal shock rupture, Hasselman theory is frequently invoked to describe the strength degradation of ceramic materials when the microstructure has a critical role in defining thermal shock resistance. It consists of several thermal shock resistance parameters

* Corresponding author at: CIEFMA, Departament de Ciència dels Materials i Enginyeria Metal•lúrgica, Universitat Politècnica de Catalunya, ETSEIB, Barcelona 08028, Spain.
E-mail address: luis.miguel.llanes@upc.edu (L. Llanes).
[1] Current address: Sandvik Mining and Construction Tools AB. Västberga, Stockholm 126 79, Sweden.

http://dx.doi.org/10.1016/j.ceramint.2016.05.024
0272-8842/© 2016 Elsevier Ltd and Techna Group S.r.l. All rights reserved.

(i.e. R parameters) that define the resistance of the material to crack initiation and/or propagation due to sudden temperature changes. Indeed, first Hasselman thermal shock parameter (i.e. the R parameter) was firstly defined by Kingery [18]. A few years later, Hasselman proposed the R'''' parameter [19] and the unified theory of thermal shock [20]. In this investigation, both Hasselman's parameters, R and R'''', are recalled for the analysis of the microstructural effects on the thermal shock behavior of hardmetals. The R parameter refers to the critical quenching temperature to induce fracture in the material and can be estimated according to:

$$R=\frac{\sigma_r(1-\nu)}{E\alpha} \tag{1}$$

where σ_r is the fracture strength, ν is the Poisson ratio, E is the elastic modulus and α is the coefficient of thermal expansion. On the other hand, the R'''' parameter describes the condition necessary for the propagation of thermal shock induced cracks and is given by:

$$R''''=\frac{1}{2(1-\nu)}\left(\frac{K_{Ic}}{\sigma_r}\right)^2 \tag{2}$$

where K_{Ic} is the fracture toughness of the material. Within this framework, Mai [3] documented a strong strength degradation of cemented carbides when subjected to abrupt temperature changes, and successfully rationalized strength loss with crack initiation (R) and crack propagation (R'''') Hasselman's thermal shock resistance parameters [20].

In addition to material properties and the critical temperature difference, there are several factors that have a relevant influence on the performance of a body subjected to thermal shock. Buessemen proposed a classification of these factors in three groups defining different issues [21]: (1) thermal shock conditions, (2) geometry of the solid body and (3) material properties. The first group includes temperature differential and heat transfer coefficient. The second one considers the size and shape of the body. Finally, the third group accounts for coefficient of thermal expansion, elastic properties, fracture strength and fracture toughness [18,21]. The shape of the body is an extremely important aspect in determining the critical temperature difference. In general, it is recommended to avoid corners and edges, since they can act as thermal stress concentrators [18,21]. Hence, the critical temperature difference to crack a specimen can be defined as the crack initiation resistance parameter, multiplied by a shape factor (S) (i. e. $\Delta T_c = R \cdot S$) [18].

From a physical viewpoint, thermal shock damage in cemented carbides has been postulated to proceed mainly through the nucleation of microcracks at the carbide-binder interface which tend to propagate avoiding the hard phase [12–15]. This is due to the large difference between the coefficient of thermal expansion of the ceramic and metallic phases and because of the high elastic modulus of the composite material. Thus, abrupt temperature changes generate significant large thermal stresses that induce the formation of microcracks at the interface between carbide and binder phases [12,13]. Maximum cooling tensile stresses are concentrated at the surface, and the magnitude of these induced stresses is a linear function of the temperature difference and the distance from the cooled surface [14,22]. In addition, the heat transfer coefficient between the coolant and the material has also a significant influence in the generation of thermal stresses. Within this context, water is found to be much more severe than silicon oil, and maximum thermal stresses are attained, when cooling hardmetals in water, at around 0.5 s after the first contact [14].

Similar to other metal-ceramic composite materials, cemented carbides exhibit a rising crack growth resistance (R-curve) behavior [23–26] related to the development of ductile bridging ligaments at the crack wake [25–27]. R-curve characteristics are strongly influenced by the microstructure, and R-curves with a more relevant increase (including a longer subcritical crack extension) are found when rising binder content and carbide mean grain size (i.e. higher fracture toughness). This crack bridging toughening mechanism translates into effective damage tolerance, becoming then a microstructural design strategy for improving the reliability of cemented carbides tools and components.

In this paper, microstructural effects on the strength degradation of cemented carbides subjected to single and repetitive sudden temperature changes are studied. In doing so, and following the approach proposed by Mai [3], experimental data is analyzed and discussed on the basis of Hasselman's parameters for the assessment of thermal shock resistance in structural materials.

2. Materials and experimental aspects

2.1. Materials and microstructural characterization

Five experimental cemented carbides grades with different combinations of binder chemical nature (Co, CoNi and Ni), binder content (medium and high), and carbide mean grain size (ultrafine, fine, medium and coarse) were selected. All samples and materials used in this investigation were supplied by Sandvik Hyperion. Microstructural characteristics of studied hardmetals are given in Table 1, and they include information on the binder chemical nature, binder weight content (V^{wt}_{binder}), carbide mean grain size (d_{WC}), carbide contiguity (C_{WC}) and binder mean free path (λ_{binder}). Within this context it is important to remark that the principal parameters used to characterize the microstructure of hardmetals are the binder volume and the carbide mean grain size. However, usually these two parameters are varied simultaneously, and consequently additional two-phase normalizing parameters are required in order to properly analyze microstructure-property correlations. Among them, the contiguity of the carbide phase, C_{WC}, and the binder mean free path, λ_{Co}, are the mostly employed ones. The former parameter describes the interface area fraction of carbides particles that is shared between them, whereas the latter refers to the mean size of the metallic phase. Binder content values are given as supplied by the manufacturer, whereas carbide mean grain size was measured following the linear intercept method in field emission scanning electron microscopy (FESEM) micrographs [28]. On the other hand, two-phase microstructural parameters, C_{WC} and λ_{binder}, were estimated from best-fit empirical equations given in the literature [29,30]. Further, it is important to remark that the investigated 10CoUF, 11CoM and 9NiF grades contain a small amount of Cr_3C_2, added as a grain growth inhibitor.

One main objective of this investigation is to correlate the

Table 1
Nomenclature, binder chemical nature and weight content (V^{wt}_{binder}), carbide mean grain size (d_{WC}) and contiguity (C_{WC}), and binder mean free path (λ_{binder}) for the investigated cemented carbides.

Specimen code	V^{wt}_{binder} (%$_{wt.}$)	d_{WC} (μm)	C_{WC}	λ_{binder} (μm)
10CoUF[a]	10.0	0.39 ± 0.19	0.46 ± 0.06	0.16 ± 0.06
11CoM[a]	11.0	1.12 ± 0.71	0.38 ± 0.07	0.42 ± 0.28
10CoC	10.0	2.33 ± 1.38	0.31 ± 0.11	0.68 ± 0.48
10CoNiM	7.5%$_{wt.}$Co-2.5%$_{wt.}$Ni	1.04 ± 0.83	0.41 ± 0.08	0.36 ± 0.29
9NiF[a]	9.0	0.83 ± 0.49	0.44 ± 0.08	0.29 ± 0.18

[a] Hardmetal grades 10CoUF, 11CoM and 9NiF include a small amount of Cr_3C_2, added as a grain growth inhibitor.

Download English Version:

https://daneshyari.com/en/article/1458710

Download Persian Version:

https://daneshyari.com/article/1458710

Daneshyari.com