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Short communication

Fracture toughness of solar-sintered WC with Co additive

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Abstract

A tungsten carbide (WC) cylinder specimen containing 10 mass% Co sintering aid was prepared under concentrated solar radiation (measured maximum temperature no higher than 1500 °C) in dynamic primary vacuum and its fracture toughness was evaluated by Vickers indentation method. In spite of very fast rates of heating and cooling applied in the solar-sintering process, fracture toughness of the prepared WC cylinder specimen was comparable to that of WC sintered piece prepared through a conventional industrial process in electric furnace under a slow heating and cooling condition. Present results together with the previously reported results for solar-sintered alumina ceramic disk appear to suggest the promising possibility of using solar radiation heating for manufacturing sintered ceramic components. © 2002 Elsevier Science Ltd and Techna S.r.l. All rights reserved.

Keywords: Tungsten carbide; Solar furnace; Fracture toughness

1. Introduction

In a preceding publication [1], we reported that flexure breaking toughness of an alumina ceramic disk specimen prepared under solar radiation heating remained comparable with that of an alumina ceramic disk specimen prepared through a traditional laboratory method in an electric furnace with relatively slow heating and cooling rates in spite of very fast rates of heating and cooling realised in solar sintering process.

In this work, WC cylinder specimen 5 mmϕ and 5 mm high with 10 mass% Co sintering aid was prepared under concentrated solar radiation and its fracture toughness was evaluated by means of Vickers indentation method. The solar sintering for the WC—10 mass% green powders compact was done in a dynamic primary vacuum to avoid undesired oxidation of the specimen unlike for alumina specimen for which the solar-sintering was undertaken in normal atmospheric environment. Fracture toughness of the solar-sintered cylindrical WC specimen was found to be comparable with that of a WC specimen prepared through conventional industrial sintering process in an electric furnace under vacuum at DURIT S.A., Albergaria-a-Velha, Portugal.

2. Experimental

2.1. Sample preparation

Tungsten carbide (WC—10 wt.% Co) supplied from DURIT S.A. in the form of green powders was used as starting material for the present experiments by compacting it into 5 mm diameter cylinder of height 5 mm by applying uniaxial pressure of about 50 MPa. As depicted in Fig. 1, solar sintering process is characterised by very rapid heating and cooling process. As in the preceding work [1], solar sintering was undertaken in the solar furnace in Uzbek Academy of Sciences but in a chamber evacuated by oil rotary pump unlike the alumina specimen sintering which was undertaken in air. Details of solar furnace heating/cooling operation might be referred to elsewhere [1]. On the other hand, conventional sintering for the reference specimen was undertaken in

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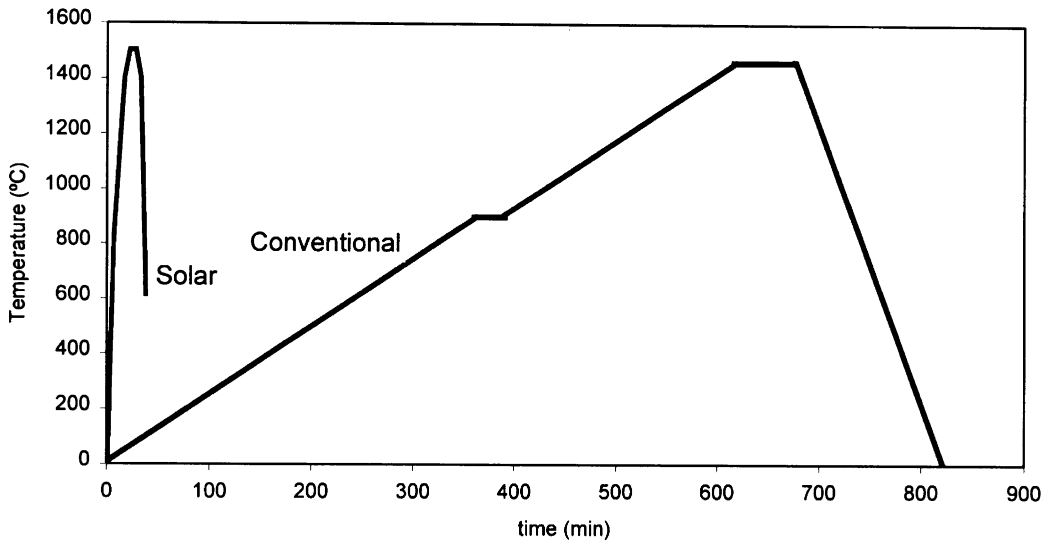

Fig. 1. Temperature profile in the solar sintering and that in the conventional industrial sintering.

an electric furnace at DURIT S.A. Temperature during the sintering process was measured by Type B Pt-Rh thermocouple being in contact with the backside of the cylinder specimen. As shown in Fig. 1, the maximum temperature reached under solar sintering process was around 1500 °C and the duration held at the maximum potential was no more than 5 min.

2.2. Specimen characterisation

2.2.1. Microstructures

Microstructure of the sintered specimens was inspected by optical microscope after being subjected to polishing with diamond paste of 1 μm and subsequent etching (Murakami's solution). A photograph of the solar-sintered specimen and that of the reference specimen sintered in the industrial electric furnace, respectively, are shown in Figs. 2 and 3.

Fig. 2. Appearance of the solar sintered WC specimen surface.

2.3. Density

Density ρ of the specimens was determined using a Helium Pycnometer (Micrometrics® AccuPyc 1330). Table 1 summarises the measured density values together with other measured parameters. Average dimension of the specimens after sintering was diameter 5.61 ± 0.15 mmϕ and height 5.49 ± 0.14 mm.

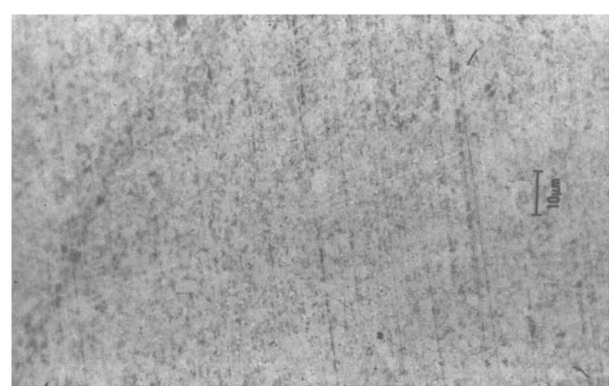

Fig. 3. Appearance of the surface of a WC specimen prepared by standard industrial sintering.

Table 1
Density, Vickers micro hardness and fracture toughness values evaluated for the sintered WC specimens

Processing	Medium density (g/cm^3)	Vickers hardness (GPa)	Fracture toughness (MPa m$^{1/2}$)
Solar	14.3 ± 0.3	13.14 ± 0.96	12.3 ± 1.5
Conventional	14.5 ± 0.2	12.56 ± 0.11	14.2 ± 0.8

2.4. Vickers microhardness and fracture toughness

In this work, fracture toughness K_{IC} [MPa m$^{1/2}$] was evaluated using the indentation fracture method. In this method, fracture toughness is evaluated from lengths of cracks propagated from four corners of a Vickers indentation mark measured using an optical microscope from the top of the surface (Fig. 4) [2].

$$K_{IC} = 0.0889\left(\frac{\mathrm{HV} \quad P}{\mathrm{Li}}\right)^{1/2} \quad (1)$$

where HV refers to the Vickers microhardness [Nm^2], P the the Vickers load ($P = 294$ [N]) and Li [m] the total crack length represented by

$$\mathrm{HV} = 1.8544\frac{P}{d^2} \quad (2)$$

$$\mathrm{Li} = \sum_{i=1}^{4} a_i \quad (3)$$

where d [m] refers to the average of the two diagonals in the base of the square indentation anda_i [m] the crack length as defined in Fig. 4. Eq. (1) is valid when the radial Palmqvist type crack [2] develops from the four indentation mark corners. In fact, all a_i ($i = 1$–4) appeared to be comparable with one another as shown in Fig. 5 and thence the employment of Eq. (1) for the K_{IC} evaluation seemed justifiable.

3. Results and discussion

Table 1 summarises the obtained mechanical characterisation results. As seen in this table, density ρ and HV of the solar-sintered WC–Co specimen were comparable to those of the counterpart prepared through traditional industrial process while K_{IC} of the former was about 10% lower than that of the latter. Mechanical properties of the latter were comparable with the corresponding literature values available for the similar specimens [3–5].

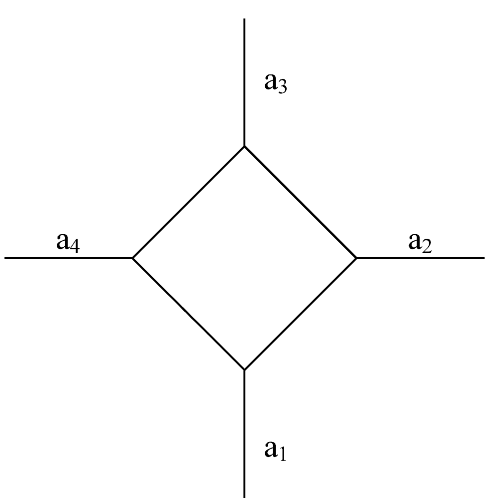

Fig. 4. Schematic of Vickers indentation and the correspondent flaw.

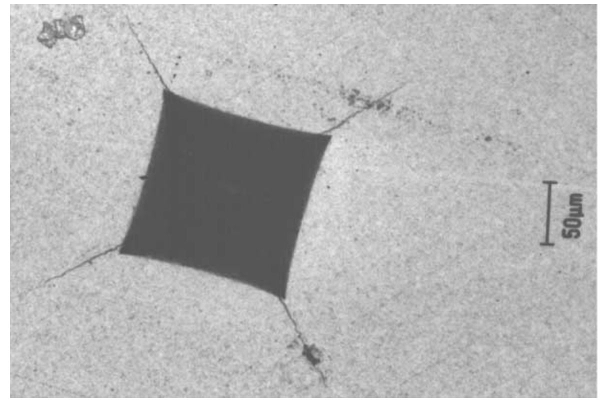

Fig. 5. Vickers indentation mark observed over a solar-sintered WC specimen.

Micrography of the solar-sintered WC-Co specimen (Fig. 2) looks also comparable with that of the WC–Co specimen prepared through the conventional industrial sintering process (Fig. 3) implying similarity in microstruture as well as mechanical properties between the solar sintered WC–Co specimen and the counterpart prepared through the traditional sintering process.

Representative area of application of WC–Co is the cutting tool for steels and cast irons and thence sintered WC–Co piece is considered as a consumable to be discarded after certain cycles of services. Thus, if the loss of mechanical property of the solar-sintered WC–Co component remains within the acceptable margin with reference to that of currently available counterparts produced by the conventional industrial manufacturing route, the solar-sintering should be accepted as the cost-effective and environmental-friendly route for producing the WC–Co sinter component as well as for the alumina sinter component [1] and for raw carbide and carbonitride powders production [6–13].

4. Concluding remarks

Results obtained in the present work are encouraging, supporting the possibility for use of a solar furnace for sintering non-oxide ceramic components like WC–Co, as well as for oxide ceramics like alumina [1]. It would be desirable to determine the threshold cooling rate yielding a flawless solar-sintered component after holding the specimen at the peak temperature for given materials as functions of component geometry and dimension.

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