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Fractography of hardmetal dies used for the manufacture of polycrystalline diamond

Roger Morrell[a,*], Ken Mingard[a], Jonee Zunega[b]

[a] Materials Division, National Physical Laboratory Teddington, Middlesex, TW11 0LW, UK
[b] Element Six Global Innovation Centre, Harwell, Oxfordshire, OX11 0QR, UK

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ABSTRACT

Some WC/Co hardmetal dies used for the high-temperature, high-pressure fabrication of polycrystalline diamond have been subjected to fractographic investigation after service failure. In each die a number of flat plate-like fragments have been found showing an unusual fountain-like appearance to the fracture surface markings. Despite extensive probing, discrete fracture origins could not be found. Instead, from the evidence of the microcracking found in the die bore region and the recognised development of deformations during a campaign, it was concluded that microstructural damage was developed under the complex non-equitriaxial compression stresses which are developed during the duty cycles. When the propagation of this damage reached the axial tensile zone that exists in the cooler regions of the die, the plate-like, more-brittle failure pattern developed.

1. Introduction

The manufacture of polycrystalline diamond components is undertaken at high pressures (5-8 GPa) and high temperatures (>1450 °C). Typically, during this process a diamond powder compact placed on a WC/Co cylinder is consolidated by the infiltration of liquid Co, which provides a medium for the development of diamond–diamond grain bonding. The resulting product is a contiguously bonded diamond layer on a WC cylinder, a 'button', which when set into a larger tool-head is used for applications including rock drilling, mining and road planing.

The process, which is well known, *e.g.* [1], and now widely employed, requires a large WC/Co die system inside which the consolidation process is sealed, and which can support the high pressures required to maintain diamond stability. Typically, the die system comprises a massive ring of WC/Co pre-loaded in radial compression by a system of steel rings (Fig. 1). Matching top and bottom conical-shaped anvils provide axial force which loads the seal materials at each conical end of the central die bore. The die contents are held in a pyrophyllite container which closely matches the bore in diameter, and are electrically heated to the required temperature while axial force is applied to the anvils to keep the system pressure sealed. The efficiency of this manufacturing process is reliant on the maintenance of die and anvil integrity. Die failures can occur, and these are process life limiting, with high cost of replacement.

This study reports a fractographic investigation to attempt to determine the causes of failures in dies in order to decide on development directions. In particular the question arose as to whether the life was limited by inadequately controlled microstructural defects within the WC/Co die body.

2. Preliminary evaluations

Having surmounted the dangerous challenge of breaking up a highly compressed die body and removing it from the retaining steel rings without inducing excessive collateral damage, it was immediately clear that the major process fractures within the die comprised two or three annular disc shapes about 10 mm thick in two zones, roughly opposite the ends of the cylindrical part of the bore, as shown schematically in Fig. 2. Relevant parts from three dies, two smaller and one large, were then selected and supplied for detailed examination. The most complete example retrieved is shown in Fig. 3.

A consistent feature of the plate-like fragments was the presence of what could be interpreted as a very large fracture 'mirror' in the centre of which was a feature with 'fountain'-like appearance of the fracture markings shown by the developing crack (Fig. 4). These markings appear to show that the crack emerged from the inner part of the die body as a narrow radially-moving fracture front

* Corresponding author.
E-mail address: roger.morrell@npl.co.uk (R. Morrell).

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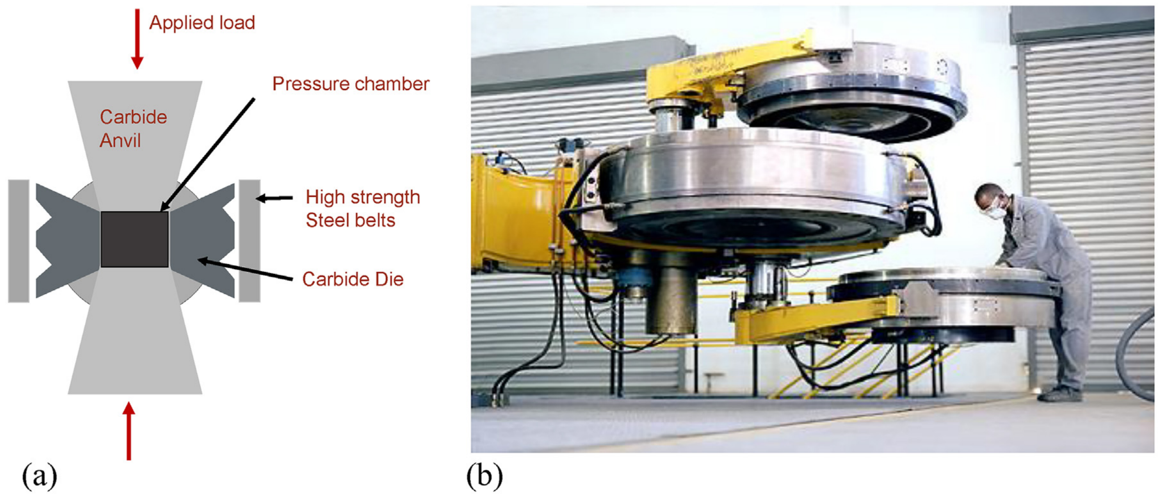

Fig. 1. (a) Schematic of the steel belt die system, and (b) an example of a PCD production facility.

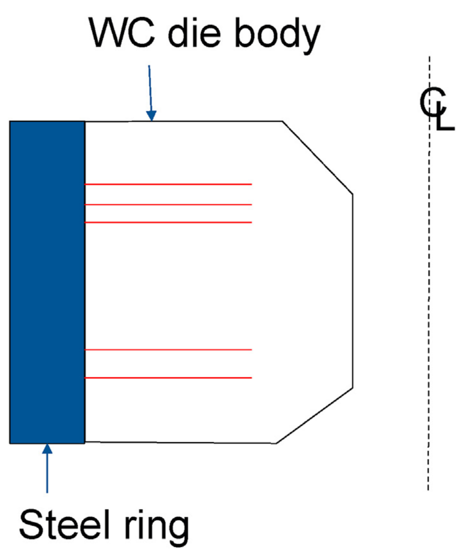

Fig. 2. Schematic of the pattern of major cracks in a failed die body.

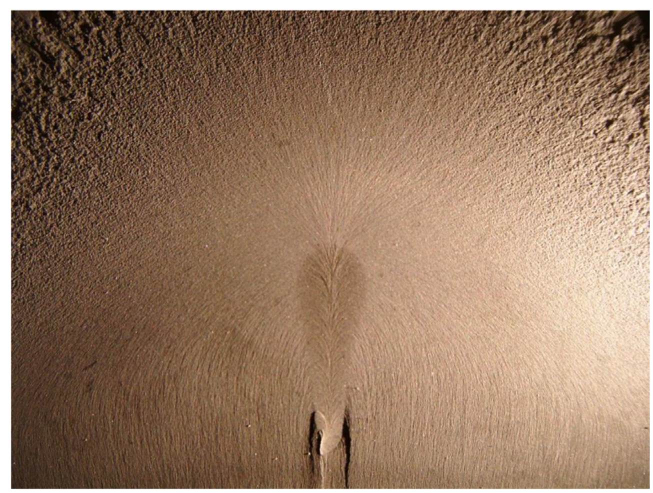

Fig. 4. A 'Fountain' crack 'mirror' showing a narrow area of microhackle emerging from the interior of the die and radiating outwards, becoming rougher as a sign of acceleration, and becoming smoother as the lower parts propagate back towards the bore.

to roughly half way through the die wall thickness, and which subsequently 'broke' into a planar 'fountain'. Parts of the fracture front accelerate away towards the outside of the die, and reach a high velocity, as evidenced by the development of strong hackle. Propagation around the remaining annulus is then very rapid. Parts of the fracture front that 'fall' back towards the die bore come to a halt at a uniform radial distance, and show minimal fracture roughness. A second such fountain from another die is shown in Fig. 5.

These fracture patterns provide some useful information; that the origin is somewhere between the observed 'fountain' and the die bore, and that final fracture occurs while high axial compression is applied to the die bore region which halts the crack running back to the bore surface. The planar nature of these cracks is also

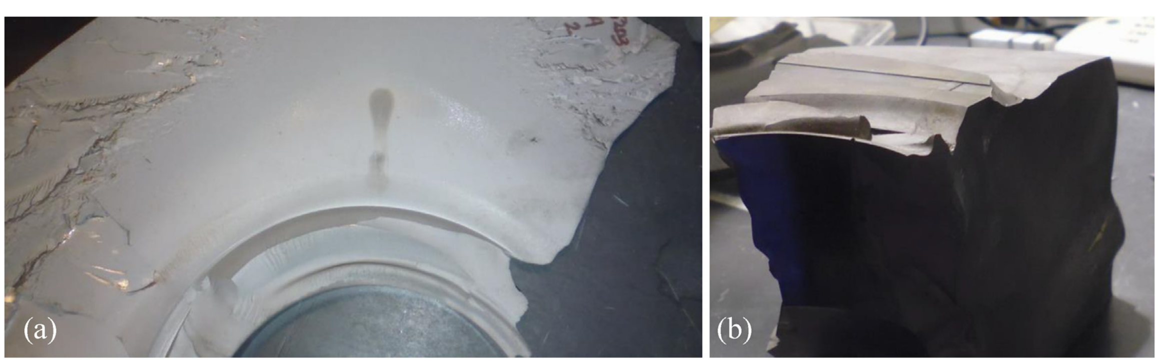

Fig. 3. Retrieved die fragments: (a) a planar region showing a distinct fracture pattern, and (b) a part of the unfractured matching bore block (inverted relative to (a)).

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