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THE POTENTIAL FOR DIAMOND FIBRE COMPOSITES

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Abstract

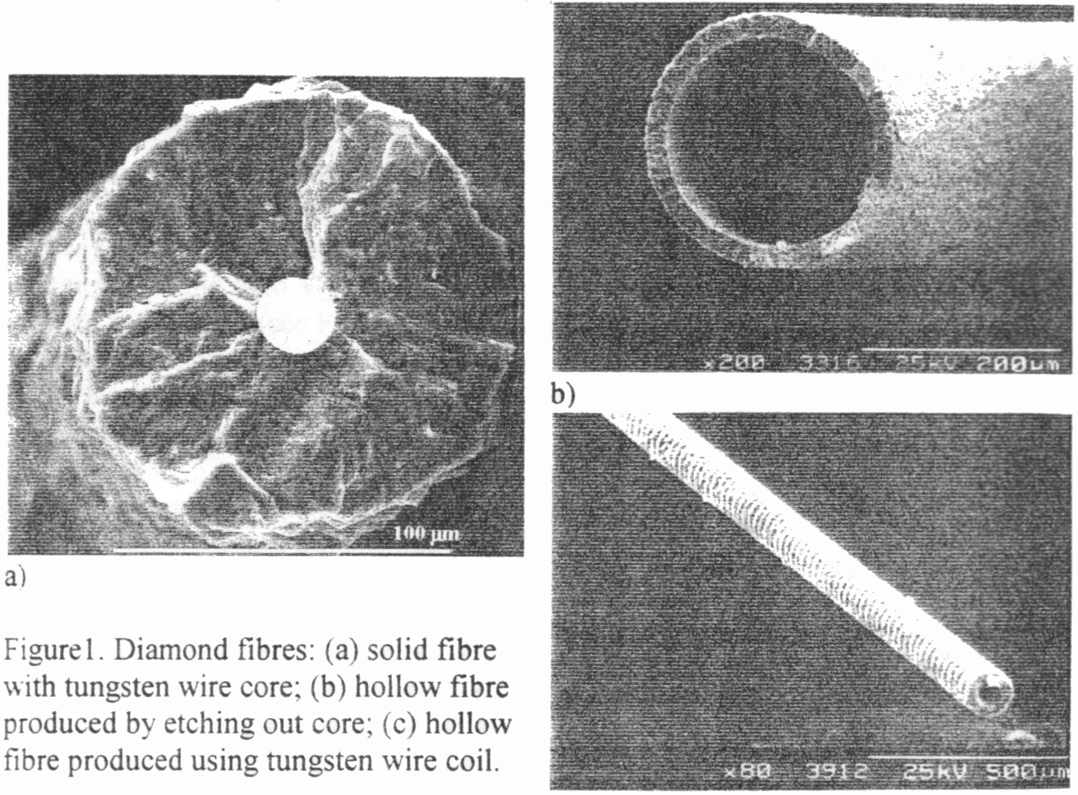
The manufacture of solid and hollow diamond fibres and of fibre arrays is described. The effective diamond deposition rate, when defined as mass per unit volume rather than in $\mu m.h^{-1}$, can be substantially greater for fibre arrays and this could lead to lower cost CVD diamond. Monofilament diamond fibres have been coated with a metallic matrix by physical vapour deposition and consolidated by hot pressing to produce metal matrix composites. Examples of diamond fibres embedded in a Ti-alloy matrix are presented.

1 Introduction

Both microwave plasma enhanced chemical vapour deposition (MPCVD) and hot filament CVD (HFCVD) processes have been used to manufacture diamond coated wires and fibres [1]. In diamond fibre reinforced composites both the physical and mechanical properties of diamond may be exploited in a single component, thereby increasing the potential for CVD diamond in engineering. The tensile modulus for CVD diamond fibre (~900 GPa) is greater, by a factor two or more, than the modulus of any other fibre except the very high modulus form of graphite fibre [1,2]. The latter has a similar specific stiffness E/ρ (E = Young's modulus, ρ = relative density) to that of diamond fibres, and lower modulus graphite fibres are now widely used both in low cost products (e.g. sports goods) and in aerospace structures. Several other high strength multiflament fibres (e.g. Nicalon and Tyranno) and monofilament SiC fibres [2] have superior oxidation resistance to diamond and graphite fibres above ca. 600 °C. Clearly therefore, quite apart from cost factors , diamond fibres will need to make maximum use of the advantageous properties of CVD diamond in order to compete with these commercial fibres.

2 Diamond fibres

Fibres have been made by CVD on to various wire and ceramic cores with diameters in the range 10 -100 µm (Fig.1a) and hollow fibres have been produced by subsequent etching of tungsten or SiC cores (Fig.1b) or by deposition on to helical tungsten coils (Fig.1c) [3]. The hollow fibre dimensions can be selected to give different wall thicknesses and core diameters and hence fibre modulus. Unlike solid fibres, the specific stiffness of hollow diamond fibres is a constant, independent of fibre dimensions and equal to that of CVD diamond [1]. Once incorporated into a composite material, these fibres would not only reduce the composite density, but could also act as cooling channels in for example, thermal management systems [4]. Thin walled fibres may also flex elastically and provide greater transverse strength.



a)

b)

c)

Figure1. Diamond fibres: (a) solid fibre with tungsten wire core; (b) hollow fibre produced by etching out core; (c) hollow fibre produced using tungsten wire coil.

3 Effective diamond deposition rates for fibre arrays

The current high cost of CVD diamond is largely determined by the low deposition rate. However the coating of multiple fibre arrays (Fig.2) may lead to a substantial reduction in the cost of CVD diamond composites.

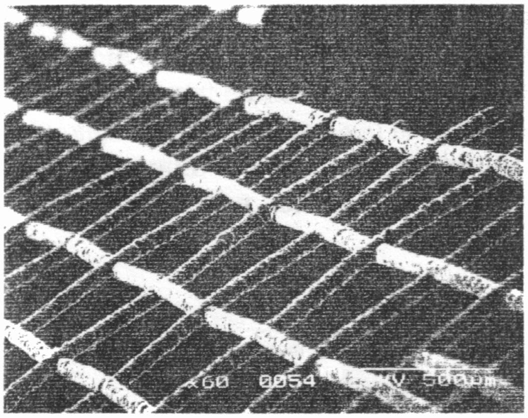


Fig 2 diamond fibre array

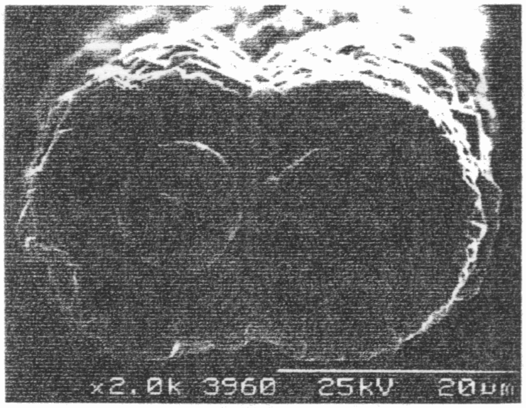


Fig 3 Two parallel fibres embedded in diamond

If we define a diamond deposition rate **R** (µm/h) = **x/t** , where **x** is the increase in deposit thickness in a time **t**, the volume **V** of diamond deposited per unit time is proportional to the total substrate area and given by, $\mathbf{V_F = x\ L_1L_2N}$ on a flat surface (of area $\mathbf{L_1xL_2}$) and by $\mathbf{V_C{=}\pi(L_1x{+}x^2)L_2N}$ on a long cylindrical surface (diameter $\mathbf{L_1}$, length $\mathbf{L_2}$) where **N** is the number of surfaces or fibres. For typical values of $\mathbf{x/L_1}$ in the range 0.1-10 the ratio $\mathbf{V_C/V_F}$ ~3.5-35. Since parallel fibres may be coated and embedded in diamond (see Fig.3), the mass of diamond deposited per unit time can be an order of magnitude greater for a row of **N** fibres compared with **N** flat surfaces with the same projected area. Greater effective deposition rates may be achieved by coating a 3-dimensional square array of fibres. Consider a square array of 100 x 100 fibre cores, each of 20 µm diameter with a spacing between the fibres of 100 µm, which are coated at **R** = 1 µm/h for 50 h, i.e. until the growing surfaces make contact (Fig.4). A normal section through the fibre diameters will be 12 mm thick, of which 10 mm will be diamond. This corresponds to an effective **R** = 10 mm / 50 h = 200 µm/h in the diametral direction. Admittedly, the section described would be 21% porous. However these model calculations do suggest that the use of different fibre shapes and spacings can lead to very high effective diamond deposition rates for fibre arrays [5]. With suitable fibre spacings, the arrays may be infiltrated with a polymer or liquid metal to produce diamond fibre reinforced composites.

4 Diamond fibre reinforced Ti-alloy composite

Commercial CVD SiC monofilament fibres about 100 µm diameter with E = 400 GPa are currently used in Ti-alloy metal matrix composites. The use of CVD diamond fibres offers various options. A direct replacement of SiC with CVD diamond could lead to higher composite modulus, or the *same* modulus could be obtained with fewer fibres or the same number of smaller diameter fibres. Compared with SiC fibres, both solid and hollow diamond fibres may lead to substantial increases in the specific stiffness of Ti-alloy composites [1].

An example of a Ti-6Al -4V alloy composite containing diamond fibres with a SiC fibre core is shown in Fig.5. After consolidation processing, carbide layers were present at the titanium /diamond interfaces, but the Raman spectrum for the diamond appeared unchanged and no cracks were detected in the diamond deposit. Diamond fibres with ceramic cores are insulators and are less likely to give rise to galvanic corrosion than, for example, graphite fibres in metal matrices.

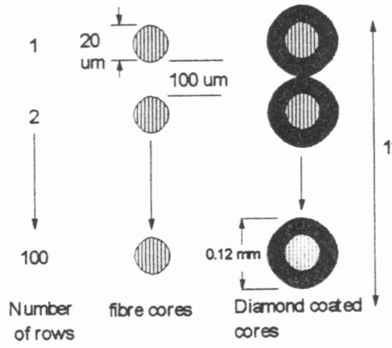


Figure 4 Schematic diagram of through thickness dimensions for cores and diamond coated fibres in a 100 fibre array (see text)

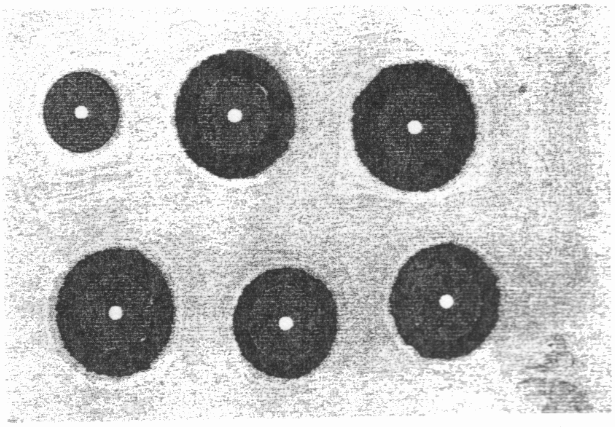


Figure 5, Section through diamond fibre/Ti-6Al-4V alloy composite, showing Sigma SiC fibres coated with various thicknesses of diamond.

5 Conclusions

There is considerable flexibility in the design of both solid and hollow diamond fibres, with different external and internal diameters and tailored elastic modulus values. Composites based on these fibres could have wide application in engineering and there is potential for a substantial cost reduction by coating fibre arrays.

6 References

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