Heterogeneous nucleation of graphite in carbon steel

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The graphitic form of carbon is a second phase mostly common to grey cast irons and mainly exists as flakes or with a spheroidal or nodular morphology [1]. It develops either during solidification or can be induced by heat treatment in e.g. white irons [2,3]. In carbon steels it is rarely observed because the formation time is extensive compared with the kinetically favoured iron carbide, Fe_3C, cementite. When graphite occurs in steel after long periods during high temperature service it is generally considered detrimental to properties and so the steel microstructure is stabilised by alloying with strong carbide formers such as chromium [4]. Nonetheless, the formation of graphite in steel destined for extensive machining, or designed to possess good machinability or cuttability, perhaps combined with good workability, could be advantageous, in that a graphitic second phase might be expected to act as an 'internal lubricant' during the very severe deformation of machining, where external lubrication is relatively ineffective. However, with such high tonnage product the times required for graphitisation are extensive and therefore uneconomic for high volume production. In consequence, free-machining steels are instead alloyed with Pb, Mn, S, P, Te or Bi to improve their machinability, but these compositions can create difficulties during manufacturing and recycling [5]. Thus, attempts have been made to enhance the graphitisation kinetics in carbon steels, which can be divided into two approaches: (i) Introduce heterogeneous nucleation sites, generally carbides, nitrides or oxides; (ii) Destabilise carbide formation by alloying with appropriate graphitising elements whilst minimising carbide forming elements [5,6]. The present paper examines the heterogeneous nucleation process, and, as it can occur during both approaches, is carried out in steel designed to follow mainly the second approach i.e. with a composition lean in carbide formers but rich in graphitisers. A strong graphitiser is Al but this element can also combine with N in the steel to form a potential nitride nucleant.

A medium carbon experimental steel similar to that studied in [6] with composition 0.39C, 1.86Si, 1.38Al, 0.11Mn, 0.010P, 0.002S 0.002N (wt.%) was provided by Tata Steel, UK. Samples were austenitised at 1150°C and normalised to a ferrite/pearlite structure before annealing at 680^{O}C for a period of 20 minutes. This treatment promoted a coarse dispersion of graphite particles mainly of irregular shape and a number were observed to have a nucleating particle at their core. These particles were examined by high resolution TEM after preparing suitable lamellae by FIB SEM. A typical graphite particle, apparently forming heterogeneously on a precipitate identified as AlN, is shown in the SEM micrograph of Figure 1(a) and the FIB lamella prepared from this complex is shown in Figure 1(b). An HRTEM lattice image from the graphite/precipitate interface region is shown in Figure 2 (a) and a magnified image of the square area indicated is shown in Figure 2 (b). The interface appears quite planar with a potential degree of coherency between the two lattices, indicating the preference for heterogeneous nucleation at AlN. It is also noticed that the initial growth direction varies from different sections of the interface, eventually rotating towards a more common growth direction and creating imperfect regions at the intervening sections.

References

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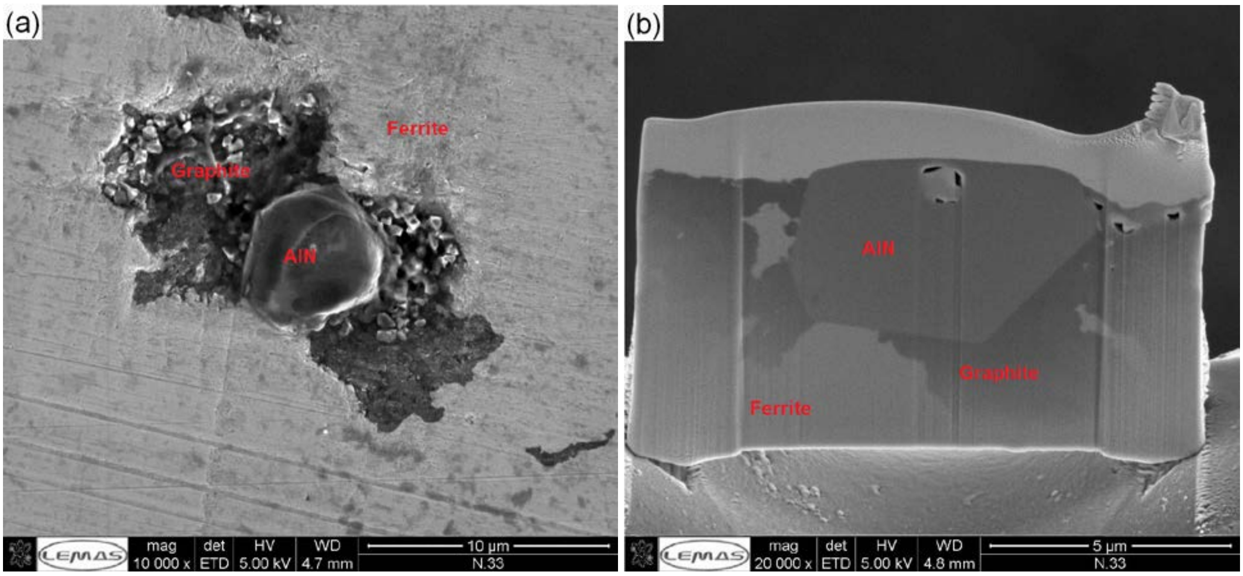

Figure 1 *(a) Graphite particle forming upon an AlN precipitate, and (b) TEM lamella prepared from the region shown in (a)*

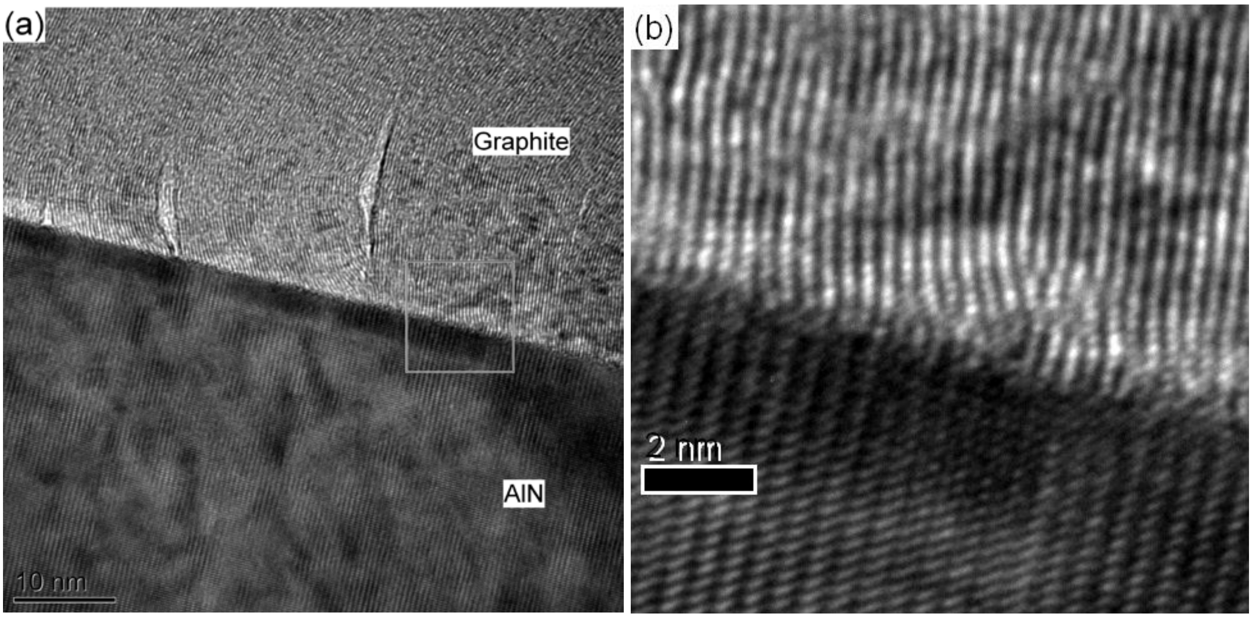

Figure 2 *(a) High resolution lattice image from the interface region of graphite and AlN, and (b) a magnified image of the interface region outlined in (a)*