1. Introduction
As environmental restrictions on the use of lubricants grow tighter, and costs associated with disposal increase, there is increasing demand for solid lubricant coatings that reduced friction and wear,

One of the most promising candidate coatings is diamond-like carbon (DLC), but use of these coatings is often limited by high process temperatures or poor load bearing capacity.

A hard, graphite-like, carbon-based coating, Graphit-iC® has been developed with exceptional tribological properties under high loading conditions. This coating demonstrates extremely low wear rates (<5 x 10^-17 m^2/Nm) and a low coefficient of friction (typically <0.07) when tested dry against steel or WC/6%Co counterparts at contact pressures of around 1 to 30GPa.

2. Coating Development
Graphit-iC® is deposited using a closed field unbalanced magnetron sputter ion plating system (Fig 1.) with two carbon targets and two chromium targets[1].

A chromium interlayer is deposited first followed by a carbon-chromium layer of graded composition (~0.2*~m) to achieve excellent adhesion. Finally the main carbon layer (~2*~m) is deposited, during which a small amount of chromium (~5%) is co-deposited to obtain high toughness and load bearing capacity.

The substrate is biased with a pulsed DC voltage during the coating process. Variations in the bias voltage applied, and the amount of chromium co-deposited (Fig. 2) can be used to optimise the coating hardness, toughness, and adhesion [2,3].

The coating hardness can be varied from over 35GPa (pure carbon) down to 10GPa. 12 to 20GPa is the range usually selected for optimum tribological performance.

3. Structure and Physical Properties

(a) TEM section and (b) selected area diffraction pattern from a standard Graphit-iC coating[2].

- Dense, amorphous coating structure (Fig. 3a and b).
- No short range order (broad diffraction rings)
- High resolution TEM can detect fine regions of nano-crystalline graphite within the amorphous carbon matrix [4].
- Raman spectroscopy detects only sp2 bonding within the coating (no sp3).
- High level of adhesion as indicated by no chipping, cracking or delamination on 150kg Rockwell C indentation test, and scratch tests to 60N with a Rockwell diamond (Fig. 4).

4. Tribological properties.

Pin on Disc tests (dry) - 200mms^-1 linear speed - 8mm track diameter. Graphit-iC coated MA2 against 5mm diameter WC/6%Co ball.

At the beginning of the test the friction coefficient is typically around 0.15 but decreases very quickly to reach a lower steady state value. This value is lower with increased test load as shown in figure 5 and figure 6.

Figures 6 and 7 show that the wear rate remains low (<2.5x10^-17 m^2/Nm) for normal loads up to 140N (over 35GPa contact pressure).

Figure 8 compares the load bearing capacity of a the Graphit-iC coating, with and without the co-deposition of chromium, to a commercial DLC (a typical hydrogenated Me-C coating).

Tribological performance is also excellent in water and oil lubricated conditions, and most non-vacuum* environments, and the coating is found to cause much less wear of contacting surfaces than conventional hard coatings such as nitrides [5].

*In vacuum environments, MoST or Dymon-iC is recommended.

5. Application examples.

- Automotive/engine components and machinery:
  - Graphit-iC coatings are in full production to provide wear resistance and lubrication for components used in fuel injection systems.
  - Further applications include heavily loaded automobile parts such as gudgeon pins, cam followers, gears and bearings.
  - Carbon based coatings are also of interest for fuel cells.

- Medical Applications:
  - Graphit-iC coatings are being developed and tested for use in artificial hipjoints. They have been shown to present no biocompatibility problems during in vitro testing and initial wear tests performed on coated CoCrMo samples suggest that it may be possible to double or triple the useful life of prostheses.

- Drilling applications:
  - Initial tests indicate that Graphit-iC coatings can increased drill life by more than seven times for dry drilling of aluminium alloys.

6. References