1. Introduction
Extruded aluminium alloy is already a ubiquitous engineering material but there is increasing demand for aluminium-based metal matrix composites (MMCs) with improved stiffness and wear resistance to further extend the material’s range of application (1). The extrusion of MMCs containing significant quantities of hard, second-phase particulates places particular demands on the die, which must obviously maintain its critical mechanical and tribological characteristics, while resisting chemical and abrasive wear during exposure to the flowing aluminium MMC under conditions of high temperature and pressure. Many advanced applications demand the fine control of both the dimensional tolerance and surface finish of the extrudate, while maximising the productive lifetime of the associated die, and minimising scrap, setup costs, etc. An advanced duplex treatment has been developed for H13 steel extrusion dies, combining gas nitriding and closed field unbalanced magnetron sputter ion plating (CFUBMSIP) (2) of high performance CrTiAlN-based coatings (3). Testing of coated substrates, using the pin-on-disc and abrasive wear testing, and the initial performance of the coatings in an industrial aluminium extrusion process, where it can more than double die life, further demonstrate the potential benefits of this coating.

2. Wear of CrTiAlN coated H13 versus Al-TiC MMC Pins
CrTiAlN (approx 6µm thick) was coated onto gaseous-nitrided (4) 100mm diameter H13 discs. To prepare the Al-TiC MMC pins a master alloy was melted, diluted and alloyed to make a 5063 alloy composite (0.7 wt% Mg, 0.4 wt% Si) containing 18wt% of 15µm diameter TiC particles. The composite was then cast into 35mm diameter cast iron moulds. The cast billets were then homogenised and extruded at 450°C, at 1mm/s, to produce 4mm rods – these were machined into ? 6mm pins, 15mm long for the wear tests. PoD conditions were: 30 N with a rotational speed of 0.2ms⁻¹ for a distance of 1km, for both the as-nitrided and CrTiAlN coated samples, tested at ambient temperature.

Using profilometry to measure the wear scar, the wear rate of the nitrided surface was estimated as 1.4x10⁻¹³ m²/N, i.e. a specific wear rate (SWR) of 4.7x10⁻¹⁵ m²/N·m. The wear of the CrTiAlN coated disc was so small that it could not be measured by this technique.

3. Wear of CrTiAlN coated H13 versus Al-TiC MMC Pins
Abrasive-slurry wear tests on the CrTiAlN coated, nitrided H13 were performed in a TCL AT-1 unit. A slurry of 4µm SiC particles, at 20vol%, in distilled water was used. The counterface was a 22mm diameter steel ball, rotating at 76 rpm, with a 0.2N normal load against the coated surface. The abrasive wear coefficients for the coating and nitrided H13 substrate were estimated as: $K_w = 5.03 \times 10^{-13} \text{m}^3/\text{N} \cdot \text{m}$; and $K_a = 8.65 \times 10^{-15} \text{m}^3/\text{N} \cdot \text{m}$, respectively.

Pin-on-disc tests were also made on the same disc using a Teer Coatings PoD-2 unit with a 5mm hardmetal (WC-6%Co) ball. The sliding speed was constant at 0.2ms⁻¹, over a 720m sliding distance. Applied loads from 2N to 30N were used. Coating wear was measured by creating ball craters in the resulting wear tracks. The results are summarised below.

4. Conclusions
CrTiAlN deposited by CFUBMSIP dramatically increases the wear resistance of gaseous nitried H13 hot work die steel in pin on disc and abrasive slurry testing. Recently the coating has been shown to more than double the life of a production extrusion die for high strength, aerospace grade, aluminium alloy (4) and work is now in hand to evaluate its practical performance in the extrusion of high TiC content Al MMC alloy.

5. References
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6. Acknowledgements
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