Materials Science of High-Strain Rate Processing and the Effect of Chemical Environment

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The development of materials for industrial applications has progressed significantly in the past fifty years with a movement away from equilibrium processing routes to enable the improvement of material microstructure, properties, and performance. Initially kinetic effects were exploited through rapid cooling to produce new non-equilibrium phases like martensite and amorphous phases which relied on the fact that there was insufficient time during processing for the diffusion processes needed to create thermodynamically stable structures. Strain energy was used to supplement thermodynamic free energy to allow such phase transformations. More recently, the use of strain energy induced by processing has been exploited in other ways to enable recrystallisation and grain refinement with the aim of reducing grain size in metals to improve mechanical properties as in thermomechanically controlled-rolled steels. This generated interest in novel high strain rate processing methods to generate raw materials on a large-scale including ball milling, equal angle channel processing and short duration energy beam impact methods. Researchers soon discovered that these processes could produce microstructures that had not been possible previously and it was possible to exploit these in industrial applications. Mechanical alloying based on ball milling of powders could be used to make materials from immiscible components which were thought to be impossible by conventional processing and, for instance, commercial corrosion-resistant alloys with good creep resistance were soon on the market to exploit this.

One common feature of all these microstructures is they are metastable and can change considerably by heat treatment or under in-service conditions to produce a range of new structures which can be exploited further. The tempering of martensite in steel to improved toughness is a desired example of this but the mechanical stresses in service (in ears and bearings) can also lead to similar changes in microstructure which is known as martensite degradation which may not be so beneficial. The formation of amorphous and quasicrystalline alloys in ball milling is another example where thigs can be advantageous. The high shear mixing of materials in tribological transfer layers can be either good or bad. The chemistry during processing also has an effect.

This presentation will briefly review the development of processing methods for non-equilibrium material microstructures focussing on examples of materials which cannot be made by conventional processing. It will highlight the area where novel materials are made and how the long-term stability of the structures produced is affected by the chemical environment during processing and service. This will be illustrated by selected industrial examples.

Professor S.J. Bull Short CV

Professor Steve Bull MA PhD CEng FREng FIMMM FInstP is Cookson Group Chair of Materials Engineering in the School of Engineering at Newcastle. He completed his PhD on ion implantation of ceramic materials at Cambridge University in 1988 under the supervision of Trevor Page. He has over thirty years' experience in Materials, Tribology and Surface Engineering research having spent eight years at AEA Technology, Harwell running coating activities before moving to Newcastle University in

1996. He has been Head of Chemical Engineering at Newcastle (2005-2010) as well as Director of Research in both Mechanical and Chemical Engineering at different times. He is currently Director of Discipline for Chemical Engineering.

His research interests lie in mechanical and tribological properties of layered and porous materials including carbon-based materials and polymers. His work combines surface characterisation and mechanical property measurement at high spatial resolution with theoretical analysis to understand and interpret the data generated. A particular emphasis of his recent work is the understanding of the effect of surface chemistry on the plastic deformation and fracture processes in multilayer coatings and the development of predictive modelling approaches to provide data for design.

He is currently working on the fracture properties of solar control coatings on glass, impact-resistant polyHIPE materials with hierarchical porosity, stress generation and stress relaxation in polymer gels and foams and mechanical assessment and design of tidal turbines. He has published over 220 papers in refereed journals (Google Scholar h-index =50) and is regularly invited to present his work at International conferences, most recently at the International Conference on Advanced Ceramics and Coatings in 2020. He has successfully supervised 27 PhD students to completion. He was awarded the Tribology Silver medal (top UK tribology award in the UK from the Tribology Trust (Institution of Mechanical Engineers)) in 2013 and was elected a Fellow of the Royal Academy of Engineering in 2014. He is currently a Fellow of the Institute of Materials, Minerals and Mining and of the Institute of Physics and is a chartered engineer. He is the chairman-elect of the Advanced Surface Engineering Division of the American Vacuum Society.