DARE

DESIGNING ALLOYS for RESOURCE EFFICIENCY

**NEWS AUGUST 2016**

Welcome to the first edition of the DARE newsletter: a quarterly update of the research activities within our EPSRC funded programme.

For Further information about the DARE programme please visit our website http://www.darealloys.org or contact:

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## High Strength Steels for Lighter Road Vehicles

### Academic visit to Volkswagen, Wolfsburg

Manufacturers in the automotive industry are looking to increase strength through the use of “Advanced High Strength Steels” produced at the same or a reduced cost. **Prof Mark Rainforth**, lead Investigator of the DARE project, recently visited Volkswagen’s R&D centre in Wolfsburg to discuss the next generation of high strength automotive steels.

New advanced high strength steels used to reduce the weight of the body in white
The transmission electron microscope shows the nanoprecipitates in the steel

In conjunction with TATA Steel, partners in the DARE project have developed a nanoprecipitation steel with outstanding strength of 1 GPa, and which shows excellent formability. New alloy design requires the interaction of atomistic scale modelling with a microscale behaviour through to full scale metals production. The DARE team has brought together a unique combination of skills to understand how to control steel structure at atomic scale, in order to provide a new commercial product. This new steel is not only resource efficient, requiring the use of less material in a car, but also contains very little in the way of alloy addition.

If successfully manufactured on an industrial scale this product could help the steel and automotive industries to contribute towards a more resource efficient and low carbon- economy.

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## High Strength Titanium Alloys

**Continuous extrusion of titanium machining chips for recycling and cost-effective reprocessing**

The aerospace industry routinely machines away over 70% of the titanium alloys it buys to make structural parts for aircraft. Due to this low buy-to-fly yield and the high

costs involved to initially produce the alloyed titanium billets, there is a huge drive to find ways of reprocessing this 'waste' metal into a functional product. The machining chips are normally cleaned, pressed into briquettes for safe transport and sent for reprocessing in steel mills where they are remelted as alloying additions. This waste recycling process is also used for a range of other metal systems, most commonly aluminium, where it can be recycled almost indefinitely through remelting and casting.

The Sheffield Titanium Alloy Research Group (STAR) at the University of Sheffield has already demonstrated the use of Continuous Rotary Extrusion (CRE) to extrude titanium powders into solid wire in a fully solid state process. From the self-canning nature of CRE and by keeping the extrusion temperature low, the uptake of elemental impurities and interstitials such as oxygen and nitrogen can be greatly limited. This technology has recently been expanded to allow the use of titanium machining swarf as feedstock. As with powders, the swarf is fed into the CRE machine under ambient temperatures and without an inert atmosphere to continuously produce solid wire. This recycled wire can then be used in further processes such as Wire Arc Additive Manufacture (WAAM) or a range of other wire-fed Additive Manufacturing (AM) techniques. The use of CRE in this way can greatly reduce the cost of wire feedstock for AM processes, further improving the manufacturing cost of the final parts.

**Dr Martin Jackson**, the academic lead on this research, is one of our keynote speakers at the **DARE Annual Symposium**; his presentation will appear on our website shortly.

Alternatively, please contact:

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## Featured Publications

**Predicting microstructure and strength of maraging steels: Elemental optimisation**

**Dr Enrique Galindo-Nava, Cambridge University.**

**Abstract:**

This work presents a thorough study on alloying additions controlling mechanical properties in maraging steels. These alloys combine exceptional properties which include high strength and toughness, high strength to weight ratio, good weldability, simplicity of heat treatments and dimensional stability. The properties stem from the complex microstructures formed during hot processing: a hierarchically arranged lath martensite matrix decorated by nano-sized intermetallic precipitates and austenite laths. The first two features dictate the strength, whilst the partial reversion from martensite to austenite greatly influences their ductility. This work is an extension of a previous modelling study which described the hierarchical structure of martensite in Fe-C steels, including dislocation density, and lath and high-angle grain boundary spacing. The dislocation density provides the preferential nucleation sites for precipitation, whereas the grain boundary spacing dictates the extent of austenite growth. Descriptions for precipitation nucleation, growth and coarsening evolution are identified on intermetallics typically present in maraging steels. The results are combined to prescribe the strength-elongation relationship at different ageing temperatures in Fe-Ni-, Fe-Mn- and Fe-Ni-Mn-based steels. A critical assessment on contributions to mechanical properties of typical alloying elements is performed: Ni and Mn control the formation of austenite, where the latter shows stronger influence on the growth kinetics. Ti additions increase strength by precipitating stronger $Ni_3Ti$, whereas Cu clusters induce low strength. Based on the “resource efficiency” philosophy, optimal process and alloy design scenarios are explored for improving ductility in maraging steels whilst preserving high strength.

**Dr Galindo-Nava** is an early career Research Associate at Cambridge University, working within DARE. For further information about the above publication please contact him at:

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## Events

### Resource Efficiency and Sustainability

Resource efficiency and sustainability are important aspects of the DARE project and we were therefore pleased to co-host the **Materials Life Cycle Analysis (LCA) Workshop** earlier this year, together with members of the Advanced Resource Efficiency Centre (**AREC**) and the EPSRC funded project "Substitution and Sustainability in Functional Materials and Devices" (**SUBST**).

Following presentations in the morning by various guest speakers, delegates split into discussion groups to determine key issues surrounding LCA and potential new concepts to take forward, including: why current materials life cycle is not sustainable; how science and research can help to make it more sustainable in the future; the stakeholders who should be involved and the support and resources required to achieve this.

One of the main messages to come out of these discussions was the role of 'behavioural economics' in climate change and how this could be mitigated using LCA as a tool to inform the public. Could LCA be used to inform policy makers and stakeholders on a greater scale than perhaps it has been previously used by applying it to a major public works, for example the high speed rail network, a high profile project which has many different aspects both positive and negative that impact on climate change and sustainability?

Everyone agreed that the day had been informative and that we should continue the discussions at future LCA workshops. Keep monitoring our website for news of future workshops on this topic.

**Prof Lenny Koh** is the Director of **AREC** and can be contacted at the address below:

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### DARE early career research associate to present at TMS 2017

Sandy Knowles, who is a DARE PDRA at Imperial College London, will be presenting his work in the 'Materials for High Temperature Applications' symposia at **TMS 2017**, **San Diego**. He will discuss the novel high strength titanium-molybdenum alloys he has been developing; he will also show his work in a poster at the **2016 DARE Annual Workshop**. Details of the design of these alloys can be found in the papers: 'Phase equilibria in the Fe-Mo-Ti ternary system at 1000°C' (doi:10.1016/j.ijrmhm.2016.07.008) and 'Phase equilibria and properties of Ti-Fe-Mo Alloys with ultra-fine lamellar microstructures' (DOI:10.1002/9781119296126.ch209).

His abstract for the conference in 2017 is below:

**Design and production of bcc titanium-molybdenum-based alloys strengthened by ordered intermetallic precipitates**

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Reinforcement of alloys with ordered intermetallic precipitates is an effective strategy for obtaining high strengths alongside damage tolerance, exemplified by nickel-based superalloys. There has been a desire to exploit this strategy in bcc-based systems; with success in some maraging steels. However, design and production challenges have limited the utilisation of ordered intermetallic precipitates within refractory-metal-based or titanium-based alloys.

This work has developed alloys with a bcc (A2) titanium-molybdenum matrix strengthened by B2 structured TiFe ordered intermetallic precipitates, by two-step heat treatments. Instructed by study of the phase equilibria in the Ti-Fe-Mo system, alloys were designed within the extensive A2-B2 phase field. Detailed characterisation showed that these contained ultra-fine A2-B2 microstructures, while compression testing has demonstrated exceptional strengths. The prospects for extending the capability of these alloys to higher temperatures will be discussed.

This work was supported through the EPSRC-DARE project (EP/L025213/1) and Rolls-Royce/EPSRC Strategic Partnership (EP/H022309/1 and EP/H500375/1).

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