Institution: University of Manchester

Unit of Assessment: UoA13a Metallurgy and Materials

Title of case study: High Performance Magnesium Alloys

1. Summary of the impact

Research at Manchester has led to the development of a new class of high performance magnesium alloys based on the addition of rare-earth alloying elements. The new alloys combine low density and the highest strength of any magnesium alloy. Used to substitute for aluminium in aerospace and automotive they produce weight savings of 35% improving performance and reducing fuel consumption. Commercialisation of these alloys by Magnesium Elektron (ME), the international leader in magnesium alloy development, contributes over $20m per annum to company revenue. This includes development of the first commercial product available for bioresorbable magnesium implants, Synermag^{TM}, launched in 2012.

2. Underpinning research

The key academics leading this activity and the period over which they contributed to the work are:

- Prof Gordon Lorimer (GWL, now Emeritus Professor), Professor of Metallurgy: physical metallurgy, alloy development. (1993-2010)
- Prof George Thompson OBE FREng (GET), Professor of Corrosion and Protection; Prof Peter Skeldon (PS) Professor of Corrosion and Protection: novel protection systems. (both 1993-present)
- Dr Joseph Robson (JDR): Reader in Physical Metallurgy: alloy development, materials modelling, wrought alloys. (2001-present)
- Dr Julie Gough (JG), Reader in Biomedical Materials Science: biomedical applications of magnesium alloys. (2004-present)

Key research staff and students who have contributed to this work are: M. A. Gonzalez-Nunez (PhD student): 1994-1997; P. Apps (PhD student): 1998-2001; R. Arrubal (PhD student): 2005-2008; R. Cottam (PDRA): 2006-2008; E. Matykina (PDRA): 2006-2009; A. Twier (PhD student): 2007-2010; R. Thornton (EngD student): 2007-2011

The impact is based on research carried out at the University in Materials from 1993 to date. This has led to a major new class of lightweight magnesium alloys that have led to a range of new applications for magnesium. Highlights of the underpinning research include:

- Design of alloy compositions that produce the highest strength ever recorded in a magnesium alloy through addition of specific rare-earth alloying elements [1,6].
- Design of alloy microstructures that are stable at elevated temperatures, essential in demanding aero-engine and gearbox applications [1].
- Understanding of the complex strengthening mechanisms in the magnesium rare-earth alloys that has been pivotal in guiding alloy and process design [1,3,4,6]. This was the first work to elucidate the effect of individual rare-earth (RE) elements on the strengthening response of magnesium alloys and suggested the potential for a new generation of high strength magnesium alloys based on exploiting specific RE elements [1,3].
- Understanding of the unique crystallographic texture development that occurs in magnesium-RE alloys and its role in producing the exceptional properties of these alloys [3].

- Development of novel protection systems to enable these magnesium alloys to be used in demanding structural applications that were previously impossible due to corrosion performance limitations [2,5].
- Development of the first environmentally-friendly corrosion protection methods for magnesium alloys that replace previous harmful (chromate) technologies [2].

3. References to the research

The research has been published in leading international journals such as Acta Materialia (the internationally-leading journal in metallurgy), Corrosion Science (the internationally-leading journal for corrosion research), and has led in part to the award of national and international prizes including the Platinum Medal of the Institute of Materials, Minerals and Mining (IoM^3) (GET 2010) and Grunfeld Memorial Award and Medal, awarded specifically for industrially significant research on alloy development (JDR 2011).

Key References

[1] P. J. Apps, H. Karimzadeh, J. F. King, G. W. Lorimer, Precipitation reactions in magnesium-rare earth alloys containing yttrium, gadolinium or dysprosium, Scripta Materialia, 48, 2003, 1023-1028. (170 citations to date, source Google Scholar) DOI 10.1016/S1359-6462(02)00596-1

[2] M. A. Gonzalez-Nunez, C. A. Nunez-Lopez, P. Skeldon, G. E. Thompson, H. Karimzadeh, P. Lyon, T. E. Wilks, A non-chromate conversion coating for magnesium alloys and magnesium-based metal matrix composites, Corrosion Science, Volume 37, Issue 11, November 1995, Pages 1763-1772. (136 citations to date, source Google Scholar) DOI 10.1016/0010-938X(95)00078-X

[3] R. Cottam, J. Robson, G. Lorimer, B. Davis, Dynamic recrystallization of Mg and Mg–Y alloys: Crystallographic texture development, Materials Science and Engineering: A, Volume 485, Issues 1-2, 25 June 2008, Pages 375-382. (81 citations to date, source Google Scholar) DOI 10.1016/j.msea.2007.08.016

Other References

*[*4] J.D. Robson, N. Stanford, M.R. Barnett, Effect of precipitate shape on slip and twinning in magnesium alloys, Acta Materialia, Volume 59, Issue 5, March 2011, Pages 1945-1956 DOI 10.1016/j.actamat.2010.11.060

[5] R. Arrabal, E. Matykina, F. Viejo, P. Skeldon, G.E. Thompson Corrosion resistance of WE43 and AZ91D magnesium alloys with phosphate PEO coatings, Corrosion Science, Volume 50, Issue 6, June 2008, Pages 1744-1752 DOI 10.1016/j.corsci.2008.03.002

[6] J. D. Robson, A. M. Twier, G. Lorimer, P. Rogers Effect of extrusion conditions on microstructure, texture, and yield asymmetry in Mg-6Y-7Gd-0.5 wt%Zr alloy, Materials Science and Engineering: A, Volume 528, Issue 24 Sept. 2011 Pages: 7247-7256 DOI 10.1016/j.msea.2011.05.075

4. Details of the impact

Context

Magnesium is the lightest structural metal, 35% lighter than aluminium, and 80% lighter than steel. It is thus a highly attractive material for manufacturing components where weight saving is critical for improved fuel efficiency and reduced emissions or better performance. However, traditional magnesium alloys suffer from three critical shortcomings; poor strength, poor corrosion resistance, and limited elevated temperature capability. Novel alloys and protection strategies, only possible as a result of research at Manchester, have produced a step change improvement in each of these areas and as a result have allowed the weight-saving benefits of magnesium to be exploited in new demanding applications in aerospace, automotive, and military applications that were previously impossible [A].

Pathways to Impact

The research described in section 2 has led to a new family of high performance magnesium which have the greatest strength and best corrosion performance of any commercial magnesium alloy, representing a step-change improvement over traditional magnesium alloys. Critical to the performance of the alloys is control of the structure on the micro-scale (microstructure). Research at Manchester has elucidated the complex relationships between the microstructure and properties [1,4,6]. Understanding the effect of each alloying addition and interaction with processing conditions enabled researchers at Manchester to design the new alloys to obtain exceptional properties [1,3,6]. Further Manchester research has led to the development of new environmentally friendly coatings enabling these alloys to be protected from corrosion in aggressive environments such as salt water [2,5]. Finally, recent Manchester work to understand the biocompatibility of these alloys was critical in the development of Synermag, the first commercial magnesium product designed for bioresorbable implants.

Reach and Significance

Impact on Materials Manufacturers

The impact described is the result of a 20-year collaboration with ME. This has led to the development to a series of commercial magnesium alloys including WE43B, WE54A, Elektron-21, Elektron-675, and Elektron-43. ME is part of the Luxfer Group, a UK based global materials technology company. They are acknowledged world leaders in magnesium alloy development, having designed over 80% of the new magnesium alloys developed in the last 30 years. These alloys contribute ~$20m per annum in revenue to ME, with 61% coming from export markets (corroborating source [B]).The exceptional properties of the new alloys has enabled ME to develop new products for the aerospace, automotive and medical markets [B]. This includes Synermag, the first commercial bioresorbable magnesium alloy product, now being produced at a new (2012) $2m dedicated production facility in the UK [B].

Impact on Aerospace and Automotive

The new alloys and associated protection systems have found extensive application in helicopter and fixed wing military aircraft that include the Westland Lynx, McDonnell Douglas MD500, F22 Raptor, Apache Mark-3 attack helicopter and the F35 Joint Strike Fighter (JSF). The 35% mass reduction enabled by using these alloys in place of aluminium is critical to meet performance and range targets. These aircraft are now being produced in large numbers, for example 3100 JSF aircraft are expected in service by 2035. WE43B and Elektron-21 are also undergoing final FAA certification for civil aerospace with applications in structural components targeted by Airbus and Boeing due to the potential for weight saving and emissions reduction. Aerospace industry calculations have demonstrated that a 10% reduction in fuel consumption and emissions will be obtained through increased used of high performance magnesium alloys in a typical large passenger aircraft [C].

Alloys Elektron-21 and WE43B have also found use in high performance wheels, gearboxes and engine castings for the motorsport industry by companies including Cosworth and Maclaren Mercedes, since they provide the ultimate in strength to weight performance at elevated temperature. An improvement in strength/weight ratio of between 20-25% is obtainable using these magnesium alloys in place of traditional aluminium solutions, saving around 10 kg from the vehicle mass, which translates to improved acceleration and braking performance [D].

Biomedical Applications

Recent (2007-present) research at Manchester revealed that in addition to their suitability for structural applications, the new family of alloys also have attractive properties for biomedical application as safe bioresorbable materials with excellent compatibility with bone. This research has led to a Magnesium Elektron patenting (2011) a new alloy (Synermag) for biomedical applications in resorbable implants. This alloy has been used to produce bioresorbable stents, wire, and screws in collaboration with a medical devices manufacturer (commercially confidential). Successful animal trials have been conducted and these products are currently undergoing certification for surgical use in humans.

5. Sources to corroborate the impact

[A] Letter from Technical and Quality Manager, Magnesium Elektron UK, confirming that the research at the University of Manchester was an essential and necessary component in the development of the range of commercial products sold today by Magnesium Elektron based on the Mg-RE alloy class.

[B] Luxfer annual review 2012 (www.luxfer.com)

[C] Aeromag: Aeronautical Application of Wrought Magnesium, EU FP6 consortium report http://www.transport-research.info/web/projects/project_details.cfm?id=11198

[D] S. Agnew, JOM, May 2004, p. 20-21, http://link.springer.com/content/pdf/10.1007%2Fs11837-004-0120-8.pdf