Institution: University of Manchester

Unit of Assessment: UoA13 Metallurgy and Materials

Title of case study: Polymers for Drinks Vending Applications

1. Summary of the impact

Research at the University of Manchester has supported the development of drinks vending systems for Mars Drinks. The research has demonstrated that a detailed understanding of the relationship between the structure and properties of the polymeric components is vital for the design and performance of two drinks vending systems, *Flavia* (single-portion fresh beverages) and *Klix* (in-cup beverages). This research has contributed to major improvements in materials selection, quality control, cost reduction and performance. These drinks vending systems were developed originally in the UK in collaboration with the University of Manchester, with *Flavia* now also manufactured in the USA and marketed worldwide by Mars Drinks with an estimated sales value of > US$400m per annum.

2. Underpinning research

The research was undertaken by:

Professor Young throughout the period 1994-2013.

Dr Patrick Fairclough (PDRA, 1995-97).

Additional research students included William O'Kane (1993-1997), Craig Meakin (1997-2001), Masakazu Tanaka (2001-2005) and Sylvain Rannou (2005-2009).

The underpinning research has been undertaken though an EPSRC and Mars-supported research programme in Manchester over the past 20 years. Findings that have contributed to the impact in this area include:

- *Rapid crystallisation processes in polymer films* [1,2]. Combined SAXS/WAXS on the Daresbury synchrotron was used to investigate the mechanism for primary nucleation in polymer crystallization [2] as previous research in this area had not been conclusive. Experiments on polypropylene with long induction times, studied by small- and wide-angle X-ray scattering (SAXS and WAXS), revealed the onset of long-range ordering prior to crystal growth. Rapid crystallization studied by melt extrusion indicated the development of well-resolved oriented SAXS patterns associated with long-range order before the development of crystalline peaks in the WAXS region. This highly-cited research has led to a completely new insight into polypropylene crystallisation that has enabled the rapid heat-sealing process in the polypropylene films to be understood and fully characterised.
- *Characterisation of molecular orientation in polymer films* [3-5]. The properties of polymer films depend vitally upon the degree of molecular orientation in the film. Polarised Raman spectroscopy is a vibrational spectroscopic technique that is used widely for the chemical and physical analyses of materials since it is both non-destructive and suitable for remote analysis. Compared to other analytical techniques, polarised Raman spectroscopy has the following advantages, (1) quantitative and precise measurement of molecular orientation distributions, and (2) study of these distributions in both the crystalline and amorphous phases. It has been demonstrated that it is a relatively rapid non-destructive technique that allows the properties of polymer films to be characterised and related to their mechanical performance.

- *Environmental stress cracking in high-impact polystyrene* [6]. Polystyrene is a widely used polymer but is susceptible to environmental stress cracking (ESC) in the presence of the fats in dairy products. It was found that high-impact polystyrene with large rubber particles gave the best ESC resistance [6]. Moreover it was shown that processing of the polymer into flat sheets by extrusion tends to damage and reduce the size of the rubber particles, worsening the ESC resistance. It was demonstrated that the appropriate choice of materials and processing conditions enables the production of samples of polystyrene with improve ESC resistance.

3. References to the research

The research has been published in leading international polymer journals such as Macromolecules and Polymer and at the 14th International Conference on Deformation, Yield and Fracture of Polymers, the top international conference upon polymer properties. It also led to Professor Young being awarded the 2012 Swinburne Medal and Prize of the Institute of Materials, Minerals and Mining (IoM^3), the premier award of the Institute for research upon plastics.

Key References

1. 'Simultaneous SAXS/WAXS and DSC Analysis of the Melting and Recrystallisation Behaviour of Quenched Polypropylene', W.J. O'Kane, R.J. Young, A.J. Ryan, W. Bras, G.E. Derbyshire, G.R. Mant, *Polymer*, **35** (1994) 1352-1358. (71 citations, WoS) DOI 10.1016/0032-3861(94)90333-6

2. 'Density Fluctuations: The Nucleation Event in Isotactic Polypropylene Crystallisation' N.J. Terrill, J.P.A. Fairclough, E. Towns-Andrews, B.U. Komanschek, R.J. Young, A.J. Ryan, *Polymer*, **39** (1998) 2381-2385. (149 citations, WoS) DOI 10.1016/S0032-3861(97)00547-8

3. **'**Polarised Raman Spectroscopy for the Study of Molecular Orientation Distributions in Polymers', M. Tanaka, R.J. Young, *Journal of Materials Science*, **41** (2006) 963-991. (31, WoS) DOI:10.1007/s10853-006-6595-7

Other References

4. 'Molecular Orientation Distributions in the Crystalline and Amorphous Regions of Uniaxially Oriented Isotactic Polypropylene Films Determined by Polarized Raman Spectroscopy', M. Tanaka, R.J. Young, *Journal of Macromolecular Science-Physics*, **B44** (2005) 967-991. (3 citations, WoS) DOI:10.1080/00222340500323599

5. 'Molecular Orientation Distributions in Uniaxially Oriented Poly(L-lactic acid) Films Determined by Polarized Raman Spectroscopy, M. Tanaka, R.J. Young, *Macromolecules* **39** (2006) 3312-3321. (10 citations, WoS) DOI:10.1021/ma0526286

6. 'Environmental Stress Cracking in High-Impact Polystyrene', S.A.D. Rannou, R.J. Young, M. Tanaka, 14th International Conference on Deformation, Yield and Fracture of Polymers, 6th-9th April 2009, Kerkrade, The Netherlands. (pdf copy available on request)

4. Details of the impact

Context

Mars Drinks is the drinks division of Mars Incorporated, a global company with a turnover of over $33bn in Petcare, Chocolate, Wrigley, Food, Drinks and Symbioscience. Mars Drinks was established in 1955, originally as the Four Square Division of Mars, and now employs more than 650 Associates across eight countries. Operating in the UK, France, Germany, USA and Japan, Mars Drinks have their drinks machines in over 35,000 businesses and produce more than one billion drinks a year with their two brands: *Flavia* single portion fresh beverages; and *Klix* in-cup

beverages [A]. A conservative estimate would value sales at > US$400m per annum. Polymers are used widely in the field of food packaging in the Mars group and the *Klix* and *Flavia* both rely upon the performance of their polymeric packaging and cups during the vending process. Collaboration with the University of Manchester over many years has enabled robust systems to be put in place to enable cost-effective and reliable polymer-based systems to be specified. Since both types of drinks are produced at the level of hundreds of millions per year, this gives major challenges in terms of materials processing, performance, and quality control.

Pathways to Impact

The impact of the contribution of UoM to this project has been through the evaluation of materials performance, quality control, trouble shooting and helping direct materials specification. This has been undertaken though Mars-funded research projects (£0.45 million over the 20-year period) with the Manchester researchers working closely with the company and with their suppliers, and spending time at the company premises.

Reach

Flavia freshly-vended drinks

A major achievement over the past 20 year period has been the introduction of Flavia, which was originally only a European product, into the export markets and more than double sales volumes [A]. Research undertaken in the University of Manchester has had significant impact upon the development of this product. Heat-sealing of the different polypropylene components has been a major challenge and the fundamental research undertaken upon the melting and crystallisation of polypropylene has led to a detailed specification of the properties needed in the different polypropylene components to produce a robust and reliable system. For example, the problem of side bursts has now been reduced by three orders of magnitude and so virtually eliminated. Consequently the *Flavia* single portion fresh beverage system has revolutionised the delivery of refreshments in the office environment. It is a simple to use, convenient, clean and reliable drinks system that has replaced the “office coffee pot” worldwide.

Klix instant drinks

The *Klix* system is now used widely in public spaces such as at colleges and in factories, delivering a range of branded drinks, both reliably and with consistent quality. The research at the University of Manchester upon the material used in the *Klix* cups has been of major significance in the development of the system. Topics studied have included polymer blends, rubber toughening, thermal conductivity and recycling. A specific example of impact was in solving the problem of environmental stress cracking (ESC) in the high-impact polystyrene (HIPS) cups used in the *Klix* system – a potential safety hazard. Polystyrene is susceptible to ESC in the presence of the fats in dairy products. This was found to be a particular issue for the *Klix* system with milky drinks such as drinking chocolate or white coffee. It was demonstrated that the ESC problem resulted from the size and form of the rubber particles in the grade of HIPS employed in the presence of dairy products. The relatively small rubber particles in HIPS were susceptible to damage during processing that reduced their effective size further. It was found that the ESC problem could be overcome by specifying a different grade of HIPS with larger rubber particles.

Significance

The underpinning research with the University of Manchester, that has led to the development of the present *Klix* and *Flavia* drinks systems has been a central and necessary component in the success of Mars Drinks [A] through:

- Better materials selection
- Improved quality control
- Improvements in packaging performance
- Significant cost reduction

One particular problem that was encountered before the collaboration with the University of Manchester was that the polymer-based components in *Flavia* and *Klix* were poorly specified in terms of their structure and properties, which meant that company was susceptible to changes in grades of polymer by their suppliers. This research has had significant impact in the areas of materials selection and quality control, coupled with an improvement in performance and an associated significant cost reduction.

5. Sources to corroborate the impact

[A] Letter Packaging Manager at Mars Drinks confirming the role of the research in the development of the Flavia® and Klix® range of drinks and the doubling of sales volume this produced.