

Institution: Queen Mary University of London (QMUL)

UOA: 13B Electrical and Electronic Engineering, Metallurgy and Materials

Case Study 3: *Improving the Safety and Performance of Commercial Tyres and other Rubber Products*

1. Summary of the impact

Research into a number of different aspects of rubber has fed into a series of extremely successful collaborations between Queen Mary and a large number of industrial partners. This has led to significant economic impacts, ranging from enhancing the performance of teams in the multi-billion dollar sport of Formula 1 Racing, to helping develop new UK designed and manufactured radial tyres for large civil aircraft. Rubber research has been undertaken continuously at QMUL for over five decades. Prof. James Busfield has led the activity since 1994, working with more than 30 major industrial collaborators, including Bridgestone, Dunlop, Red Bull Racing F1 and TARRC, who have applied our research and employed our researchers to achieve commercial and competitive advantage.

2. Underpinning research

Prof. James Busfield has led a group of researchers who have each explored different aspects of rubber performance, much of it funded through industry-sponsored projects.

The largest sponsor over the last 20 years has been Bridgestone (the largest rubber product manufacturer in the world with some 140,000 employees). Bridgestone fully funded 4 researchers and financially supported several others who were working on projects that have made a difference to the performance of Bridgestone's tyres. For example:

- Dr. Akutagawa (1993-1995) worked on understanding how various different fillers and extender oils impact the viscoelastic energy dissipation in tyre compounds, with the overall aim of reducing the rolling resistance of tyres and hence improving the fuel economy of vehicles.
- Dr. Tsunoda (1999-2001) worked extensively on understanding the tear behaviour of rubber [1] to improve the strength, abrasion and fatigue properties of tyre or hose products.
- Dr. Yamaguchi (2000-2002) examined changes to filler structure under strain in an elastomer using both mechanical and novel electrical resistivity measurements [2], aiming to simultaneously improve friction properties in tyres and reduce rolling resistance.

In addition several other researchers at QMUL, all supervised by Busfield, have undertaken projects that aim to understand the fundamental issues of increasing friction in a tyre (to enhance safety in a car tyre or to reduce lap times in a racing car) whilst reducing rolling resistance and improving fatigue and abrasion resistance. The various programmes have sought to examine the fundamentals of friction modelling (Stratford-Devalba, in post; Gabriel, 2010), abrasion [5] (Wu, in post; Liang, 2007), fatigue failure [4] (Baumard, in post; Papadopoulos, 2006; Tsunoda, 2001; Ratsimba, 2000), viscoelastic energy dissipation [3] (Tunnicliffe, in post; Suphadon, 2010; Deeprasertkul, 2000; Akutagawa, 1995) and polymer filler interactions that relate to all the above (Lowe, 2012; Jha, 2009; Hon, 2005; Yamaguchi, 2002). This predictive work to examine each of these features has been widely adopted in the industry by Bridgestone and their competitors and it has also allowed us to work with a wide range of different partners in related areas. This includes Formula 1 teams such as Red Bull F1 for whom we developed a realistic friction model (Gabriel, 2009) so that they could better understand and model the frictional effects in F1 tyres as well as SuperAguri F1 (Liang, 2007) for whom we modelled, using realistic finite element tyre models, the detailed contact patch geometry between the tyre and the race track for a wide range of suspension set ups for every position around a race track and used throughout the F1 calendar.

3. References to the research

1. Tsunoda, K; Busfield, JJC; Davies, CKL, Thomas, AG 'Effect of materials variables on the tear behaviour of a non-crystallising elastomer', J. Mater. Sci. (2000) 35(20): 5187-5198.
2. Yamaguchi, K; Busfield, JJC; Thomas, AG 'Electrical and mechanical behavior of filled

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- elastomers. I. The effect of strain', J. Polymer Sci. Part B. (2003) 41(17): 2079-2089.
3. Busfield, JJC; Deeprasertkul, C; Thomas, AG 'The effect of liquids on the dynamic properties of carbon black filled natural rubber as a function of pre-strain' Polymer, (2000) 41(26): 9219-9225.
 4. Busfield, JJC; Jha, V; Liang, H; Papadopoulos, IC and Thomas, AG, 'Prediction of fatigue crack growth using finite element analysis techniques applied to three-dimensional elastomeric components', Plastics Rubber and Composites, (2005) 34(8): 349-356.
 5. Liang, H; Fukahori, Y; Thomas, AG; Busfield, JJC 'Rubber abrasion at steady state', Wear (2009) 266(1-2): 288-296.
 6. Jha, V; Hon, AA; Thomas, AG; Busfield, JJC 'Modeling of the effect of rigid fillers on the stiffness of rubbers', J. Appl. Polymer Sci. (2008) 107(4): 2572-2577.

Funding: This work has attracted £475k of industrial funding since 2008

4. Details of the impact

The work carried out in Queen Mary's Rubber Research Group has informed the development of automotive engineering processes, leading to direct economic impacts for a number of manufacturing companies. .

The collaboration between Red Bull F1 and QMUL allowed tyre models to be made as building block components of a state-of-the-art vehicle simulator, which included for the first time an accurate tyre model. A former Vehicle Dynamics Engineer at Red Bull F1, who is currently the Tyre Team Leader at Caterham F1, sponsored a research project whilst at Red Bull F1 that involved QMUL developing a realistic friction model commented "The model is still used and has clearly contributed to Red Bull's world championship successes in F1". He went on to say "A particular benefit of our collaboration with Queen Mary was the access we gained to their other research activities. Specifically, Queen Mary has been at the forefront of research into tyre 'graining' [5]. This is an especially difficult problem to analyse, and Queen Mary's work in this area has given great insight. I have several papers published by Queen Mary, on subjects such as rubber crack growth [1], rubber abrasion [5], rubber friction, and the rubber to surface interface. I regularly refer to these, and use them in my current role within the Caterham F1 team".

Ken Yamaguchi of Bridgestone has commented that: "The greatest contribution [from Queen Mary] has been in helping us understand how to develop lower rolling resistance tyres [3] to reduce fuel consumption. In particular the detailed microstructural and micromechanics models [2,6] have provided a significant stimulus which has resulted in us undertaking extensive work in house using a similar approach to the one at QMUL of adopting a computational model to help design rubber compounds at the nano-scale". Through this approach Bridgestone became the first tyre manufacturer to gain the new EU A/A rating for their [Ecopia EP tyres](#) in October 2012, with top A grades on both fuel efficiency and wet grip. By switching to Bridgestone Ecopia tyres the average European car can save up to 70 litres of fuel per year (9,000 miles/year) which will reduce CO2 emissions by 160 kg. Or in other words if all new cars registered in Europe (15 million) ran on Ecopia EP tyres this would save up to 1 billion litres of fuel and reduce total CO2 emissions by 2,3 million tons per year (equivalent to 0.5% annual UK CO2 emissions).

The Materials Development and Testing Manager of [Dunlop Aircraft Tyres](#) has commented that the project collaborating with QMUL has helped them make significant progress in their efforts to develop radial tyres for civil and military aircraft and bring them to market. He comments that, "Adopting the fracture mechanics characterisation based upon earlier work done at QMUL [4] and coupled with finite element modelling, they were able to resolve many problems and build tyres capable of meeting the stringent qualification testing required prior to installation on aircraft. These efforts have resulted in our radial tyres for Embraer 190 and ATR 42 aircraft being widely used". It is anticipated that tyres for the Embraer 170, ATR 72, JSF and Airbus A320 will be installed on aircraft in the near future creating a solid platform for further development on radial tyres for a range of other aircraft in the coming years. He adds, "This has helped us generate significant new business for the UK in the design and manufacture of radial aircraft tyres".



Rubber research at QMUL has assisted in the development of [Bridgestone's Ecopia tyre](#) (left) that combines A rated wet grip with A rated fuel economy, and [Dunlop's radial aircraft tyre](#) (right).

The Head of the Engineering Design Group at TARRC, commented that: "Our collaborations with QMUL have allowed TARRC to make much more effective use of finite element analysis techniques to predict the behaviour of components in service. This knowledge allows us to design rubber components ranging from vibration mounts that support large engineering structures such as the new Penang Bridge in Malaysia, to much smaller anti-vibration mounts used in automotive applications".

A former chief R&D Engineer at SuperAguri F1 who now works at Mercedes F1 has commented that the collaboration with QMUL allowed a detailed understanding of how tyre road interactions are developed in F1 for the first time. This impacted SuperAguri's understanding of how to optimise the suspension configuration to improve performance. He goes on to say: "The project was extended at SuperAguri using a Queen Mary PhD graduate to undertake track side analysis. This type of modelling was pioneering at the time and is now standard practice amongst most F1 teams". The fact that a QMUL graduate was employed by SuperAguri F1 as a result of successful research collaboration leads to the significant secondary impact described in this case. Many QMUL researchers have taken up roles at Queen Mary's industrial partners, facilitating knowledge transfer and benefiting the UK economy.

Drs Keizo Akutagawa, Katsuhiko Tsunoda and Ken Yamaguchi joined Bridgestone after completing their research project at QMUL. By 2010 all three had been promoted to the highest senior research position (Research Fellow), of which there are fewer than 20 within the company, which has 140,000 employees. All three have gone on and continue to develop the techniques that were initiated as part of their studies at QMUL and have embedded their use in materials development processes that are used at Bridgestone.

TARRC also employs two former Rubber Research Group researchers, Julia Gough (2000) and David Lowe (2012) and is in contact regularly with two further former researchers Azura Rashid (2003) and Asri Ahmad (2002) who work with or for their parent company (RRIM in Malaysia).

5. Sources to corroborate the impact

- Dr. Ken Yamaguchi - Fellow at Bridgestone Corporation.
- Dr. Keizo Akutagawa - Fellow at Bridgestone Corporation.
- Concept Stress Engineer at Mercedes-Benz Grand Prix Ltd. (formerly at SuperAguri F1).
- Tyre Team Leader at Caterham F1 (formerly at RedBull F1).
- Head of Engineering Design at TARRC.Materials.
- Development and Testing Manager at Dunlop Aircraft Tyres.