Institution: University of Nottingham

Unit of Assessment: 15 General Engineering

Title of case study: Passively safe street furniture

1. Summary of the impact

Dr Richard Brooks and his team at the University of Nottingham have been investigating the high strain rate behaviour of composite materials since 2003. This has led to the development of two products that are being installed in streets in the UK and Ireland by East Midlands SME Frangible Safety Posts Ltd. The direct benefits to the company have been: the installation of 900 products in the UK and Ireland; saving of £17k capital cost and 2 months in terms of time to market per product developed and; raising of £1.8M investment to bring the products to market
At least one life has already been saved in the Shetland Islands as a direct consequence of the product behaving in the way it was designed to.

2. Underpinning research

Dr Richard Brooks (Associate Professor, University of Nottingham, 2003 - present) and Dr Kevin Brown (Research Associate, University of Nottingham, 2003-2013) have been investigating the impact behaviour of composites at the University of Nottingham since 2003. This was developed to cover the strain rate sensitivity [2.1] where the time dependent damage nature was identified as having significant effects on the behaviour of the composite material.

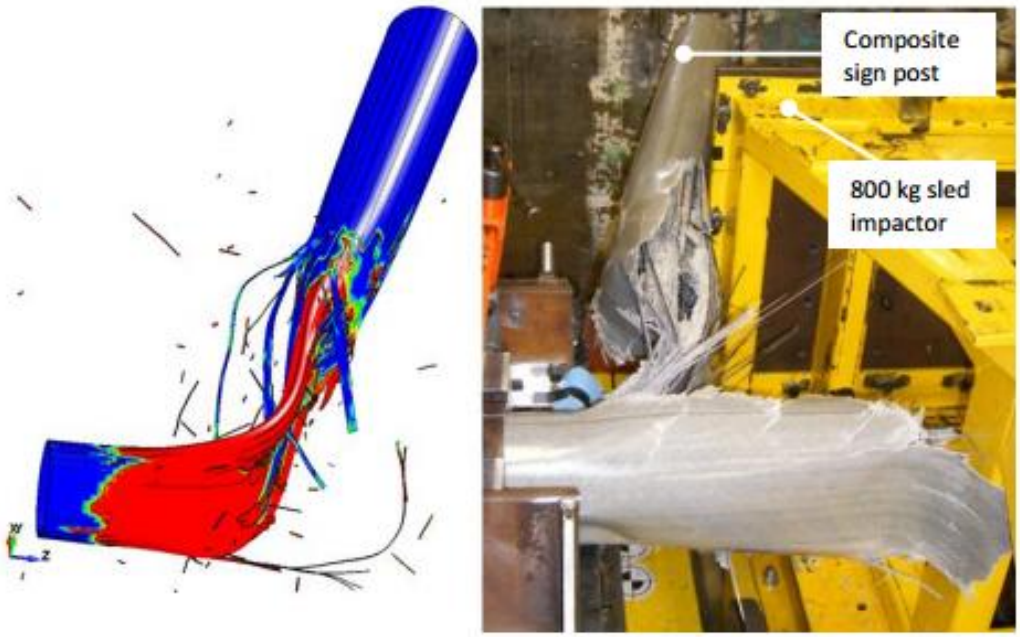

Figure 1: Finite element model showing material behaviour of sign post under crash conditions (left); Physical crash test of same material performed at UoN labs (right). Note: excellent replication of model by physical test.

This led to further work in 2006 to predictively model the impact response of more complex thermoplastic composite sandwich structures [2.2] where three point bending tests of composite sandwich structures (fibre-reinforced thermoplastic skins and a polymer foam core made from the same thermoplastic material) were performed and numerical schemes were developed and implemented using finite element code (see Figure 1, left).
This work was validated on several prototype components including a novel wind turbine blade and a safety critical rail component. The work was developed further in 2008 to investigate the microscopic damage and relate this to observed meso-scale (lab) and macro-scale (field) phenomena [2.3].
The research presented related to strain rate behaviour of thermoplastic and thermoset composites mapped directly to the behaviour of structures when subjected to impact such as when vehicles

crash into composite structures. This translated into a collaborative piece of work, funded through the East Midlands Development Agency's Transport iNet scheme, to develop the next generation of passively safe composite posts with Frangible Safety Posts Ltd. This project (CompSafe) centred on using the High Performance Computing (HPC) facilities at the University of Nottingham to simulate the impact behaviour of different composite material compositions to find the best solution using the MAT 162 model (see below) in LS-DYNA-explicit Finite Element Analysis software.

MAT162 is an advanced elastic-damage model capable of simulating complex multi-modal failure in both unidirectional and plain weave composites. It requires a total of 34 materials properties and numerical modelling parameters. Complexity is added from the nature of the hybrid structure because each constituent has its own set of properties which require definition. Over 100 input parameters were required to model the hybrid structure. A calibration method developed by Brown [4] was used to obtain appropriate values for these parameters.

The validated full scale crash model, as shown in Figure 2, provided the platform to develop a design guide for passively safe hybrid composite posts. The design guide aims to enable evaluation of the feasibility of variations in the design of the composite post against the European Standard EN12767 limits for ASI (Acceleration Severity Index) and THIV (Theoretical Impact Velocity). The design parameters investigated included: Number of carbon tows; Layup variation; Wall thickness variation; Post diameter; Foundation type (granular sub base, sand, concrete).

Figure 2: Finite element simulation of whole car crashing against sign post

Simulations of the validated crash model were made for each design option. The ASI and THIV results were plotted for each design alteration. This analysis indicated that the level of hybridisation within the composite profile can have a significant effect on the impact performance characteristic and that the designer can use this parameter when considering products for alternative energy absorption categories.

As a result of working on CompSafe with the University of Nottingham, Frangible Safety Posts Ltd has adopted the design guides to develop the products described in Section 4. Structural properties of the resulting products were also tested at the University of Nottingham (see Figure1, right).

3. References to the research

References *(Items marked with an asterisk indicate 3 most significant outputs)*:

2.1 *Brown, K., Brooks, R. and Warrior N. A., 2010, The static and high strain rate behaviour of a commingled E-glass/polypropylene woven fabric composite, *Composites Science and Technology*, 70, 272-283. DOI: 10.1016/j.compscitech.2009.10.018

2.2 *Brooks, R., Brown, K.A., Warrior, N.A. and Kulandaivel, P.P., 2010, Predictive modelling of the impact response of thermoplastic composite sandwich structures, *Journal of Sandwich structures and materials*, 12:449 (originally published online 10 June 2009) DOI: 10.1177/1099636209104537

2.3 *Lidgett, M., Brooks, R., Warrior, N. and Brown, K.A., 2011, Virtual modelling of microscopic damage in polymer composite materials at high rates of strain, *Plastics, Rubber and Composites*, 40(6/7), 324-332. DOI: 10.1179/1743289810Y.0000000007

2.4 Brown, K.A., 2007, Finite element modelling of the static and dynamic impact behaviour of thermoplastic composite sandwich structures, PhD thesis, University of Nottingham, copy available on request

Grants:

Brooks R, Competitive Design of Passively Safe Composite Profiles for Transport Safety (CompSafe), Transport iNet, http://www.transport-inet.org.uk/portfolio/epl-composite-solutions-and-frangible-sign-posts-ltd/

4. Details of the impact

The University of Nottingham's research into the high strain-rate behaviour of composite metals has resulted in significant industry engagement and adoption, economic benefits and – as already demonstrated in a real-life setting – major improvements in safety. This has resulted in faster and cheaper development of the 168mm and 219mm diameter sized street posts [4.1], which were formally launched in June 2010. As of March 2013, 900 are installed in the UK and Ireland [4.2]

The University of Nottingham, through the involvement of Dr Brooks and Dr Brown, has played a central role in the development of these two products, providing numerical simulations of high strain rate behaviour that have resulted in the specific material composition of the street posts. Sales of these two products account for 60% of the company's revenues and 50% of the profits. 6 jobs have been created to produce, sell and install these products [4.2].

Key outcomes resulting from the underpinning research include [4.2]:

1. Use of the pendulum testing methodology (the term used to describe the virtual testing methodology, the development of which is described in Section 2) to replace full vehicle crash testing. Pendulum testing alone: estimated cost savings of up to 70% per result. Elapsed time estimated savings of up to 83% per result.

2. Use of the design guide to replace full vehicle testing within iterative product development. Use of the design guide during product development: estimated cost savings of up to 90% per result. Elapsed time estimated savings of up to 93% per result.

3. Use of the design guide and computer simulation to replace full vehicle testing for product accreditation. Use of the design guide & simulation for full product accreditation: estimated cost savings of up to 72% per result. Elapsed time estimated savings of up to 62% per result.

Savings in bringing the products to market as a result of the modelling work done by the University of Nottingham amount to approximately £17k per product through minimising the number of physical crash tests that had to be performed and 2 months were saved in terms of the time to market. In the future this could increase to £99.6k and 4 months saving if the modelling fully replaces vehicular crash testing [4.2].

Figure 3: Picture of the real crash test simulated in Figure 2

Furthermore, the research provided valuable data that was used to secure an investment of £1.8m from Ahlstrom Capital (one of Finland's biggest private equity investors, portfolio turnover exceeding €1Bn) to bring the product to market [4.3].

In addition to the economic impacts, there has been at least one clear example of the improvements in safety offered by these products: A vehicle struck one post of a two post Frangible Safety Post installation and the driver walked away unscathed. It is likely that, should the vehicle have struck a traditional steel post installation, the driver would have suffered significant injuries [4.4].

FSP had their posts installed throughout the Shetland Islands in 2010 and 2011 [4.5] and commenting on this accident Neil Hutcheson, Roads Engineer at Shetland Island Council said:

"We recently renewed a large number of advanced direction signs and took the opportunity to replace the existing steel posts with the passive safety equivalent supplied by FSP. This incident has shown that to be the correct decision. I have no doubt that the vehicles occupant would have been seriously injured if we had retained the steel posts. We consider that these passive safety posts can play a significant part in reducing casualty rates and making Shetland's roads safer" [4.4].

On the 4th December 2012 in icy conditions there was an accident on the A970 on the Shetland Islands. A vehicle struck one post of a two post Frangible Safety Post installation and the driver walked away unscathed. It is likely that should the vehicle have struck a traditional steel post installation the driver would have suffered significant injuries. The Frangible Safety Post that was struck performed and reacted exactly as intended through our patented design. [4.4]

Figure 4: Damaged post and car as result of Shetland Islands incident

5. Sources to corroborate the impact

4.1 http://www.fsp-ltd.com/docs/june2010/fsp_launch_new_products_10.06.10.pdf
4.2 Dr Nick Weatherby, Technical Director, EPL Composite Solutions Ltd
4.3 Ahlstrom annual report (page 21) available at http://www.ahlstromcapital.com/PDF/ACOY_Annual%20Report%202012.pdf
4.4 http://www.therichworks.co.uk/more_info.asp?current_id=2155 - an independent, non-competitive site that provides everything you need to know about construction and highways in the UK. Endorsed by the Highways Agency and leading contractors such as URS.
4.5 Dr Gerry Boyce, Director, Frangible Safety Posts Ltd.