Institution: Liverpool John Moores University (LJMU)		
Unit of Assessment: UOA13		
Title of case study: Prolonging the Life of our Roads and Highways with No CO_2 Emission Construction Materials		
Period when the underpinning research was undertaken: 2001-2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Prof Hassan Al Nageim	Professor of Structural Engineering	1989 to present
Dr Claire Harris	Senior Lecturer	Sept 2000 to present
Dr Linda Seton	Reader	October 2001 to present
Nicola Dempster	Senior Research Officer	March 1991 to present
Dr William Atherton	Senior Lecturer	December 1982 to February 2020
Period when the claimed impact occurred: August 2013 – December 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Research in the Built Environment & Sustainable Technologies (BEST) Research Institute at Liverpool John Moores University (LJMU) allows sustainable and low-cost repairs, surfacing and maintenance of the existing asphalt, reducing the need for a complete resurfacing of roads. The application of thin layers postpones major repairs for several years and is suitable for all types of roads, therefore reducing the costs of major reconstruction works as well as reducing CO_2 emission and preventing disruption to infrastructure users. Since developing new products based on the research at LJMU and developed with LJMU, Colas Ltd has increased annual sales by over €7M in the UK and France through laying over 850,000 m^2 of roads in 2018 and 2019 using the new product, with similar projections for 2020.

2. Underpinning research

The LJMU Research Team comprises Professor Hassan Al Nageim (Lead) and Dr Clare Harris from the Civil Engineering Department, Linda Seton and Nicola Dempster from the School of Pharmacy and Biomolecular Sciences and Dr Howard Robinson, Managing Director of ASI Solutions as an external advisor. This multi-disciplinary team, supported by seven PhD students, have spent twenty years at LJMU working in the field of improving the properties of hot mix asphalt (HMA), culminating in 2 granted patents (PT1 and PT2). The research behind these patents sparked interest and collaboration with companies including Colas Ltd, Tarmac Ltd, and Velocity UK Ltd. This collaboration led to the team's research focusing on (i) zero CO_2 emission cold mix asphalt (CMA) using secondary cementitious materials (SCM), (ii) micro-asphalt (EF1), and (iii) bituminous emulsions for roads and highways surfacing (EF2).

The team responded to environmental and industry needs, namely: (i) sustainable development (the use of CMA to reduce CO_2 emissions by up to 85% and a reduction of fume exposure by 100%); (ii) asphalt production improvements (simplified cold mix plants, produced on site (i.e. mobile plant), longer storage period); (iii) cost effectiveness (no heating for storage or mixing, use of industrial waste materials); (iv) improving engineering properties (high stiffness modulus, high rutting resistance and high fatigue resistance); and (v) improving durability compared to traditional hot mix asphalt (high resistance to rainfall and water).

The team focused in particular on researching the properties of CMA (Cold Mix Asphalt), which can be prepared and constructed at ambient temperature, is cheaper to produce, easier to transport and has no health and safety issues compared to HMA. This was achieved by experimenting with different waste streams to formulate new cold bituminous emulsion mixtures

(CBEM) (UR1) similar to what had been achieved with HMA in PT1 and PT2. This then led to experiments comparing the mechanical strengths between these new mixes along with the traditional HMA methods (UR2) and then comparing different waste streams to improve the curing times of CMA to make it comparable to HMA (UR3). The combined lab results of all of these components are reported in UR4, which was the start of a KTP (EF1) with Colas Ltd taking this research forward to a new product for Colas.

Hot mix asphalt produces 221kg of CO_2 / tonne during the mixing and paving process, whereas CMA has zero CO_2 emissions during mixing and paving. The UK produces 26 million tonnes of HMA per year. However, to date and since 1957 when CMA was first introduced in the USA, conventional CMA has not had the durability and mechanical strength of HMA and has a long curing time (2-24 months) and is therefore restricted for use only in footways and lightweight trafficked pavements. In response to a request from the Tarmac R&D Managing Director in 2000, to explore green and cheap technologies to challenge the restrictions imposed by road engineers on the use of conventional CMA, the LJMU research team provided, for the first time worldwide, CMA containing secondary cementitious materials from waste ashes suitable for road and highways asphalt structural layers with a curing time of less than 1 day, a stiffness modulus 27 times more than a mixture with commercial limestone dust after 3 days, and with significant resistance to rutting in wheel-track tests at high temperatures. These results are much better than the two grades of hot asphalt concrete binder course (currently used by road engineers) meaning it can carry heavy traffic loads in hot climate conditions.

The research team continued to research and develop a new fast-curing and environmentally friendly cold asphalt concrete for binder courses mixture (CACB) following the success of EF1. The result (UR5 and UR6) is a mix that has the same gradation as that of traditional hot asphalt concrete mixtures but incorporates a binary blended cementitious filler (BBCF) containing waste, high calcium fly ash (HCFA) and fluid catalytic cracking catalyst residue (FC3R) activated by a waste alkaline NaOH solution. The benefits of the new mixture are significantly improved mechanical properties including water susceptibility, and a substantially lower thermal sensitivity than traditional hot asphalt concrete binder course mixtures.

3. References to the research

Underpinning Research (UR) outputs (all papers have been through a rigorous peer-review process):

UR1. Al Nageim, H. K., Al-Busaltan, S. F., Atherton, W. & Sharples, G. (2012) “A comparative study for improving the mechanical properties of cold bituminous emulsion mixtures with cement and waste materials.” *Construction and Building Materials*, 36, 743-748. doi:10.1016/j.conbuildmat.2012.06.032

UR2. Al-Busaltan, S., Al Nageim, H., Atherton, W. & Sharples, G. (2012) “Green Bituminous Asphalt relevant for highway and airfield pavement” *Construction and Building Materials*, 31, 243–250. doi: 10.1016/j.conbuildmat.2011.12.065

UR3. Al-Hdabi, A., Al Nageim, H., Ruddock, F. & Seton, L. (2013) “A novel cold rolled asphalt mixtures for heavy trafficked surface course”. *Construction and Building Materials*, 49, 598-603. doi: 10.1016/j.conbuildmat.2013.08.073

UR4. Al-Hdabi, A., Al Nageim, H. & Seton, L. (2014). "Superior cold rolled asphalt mixtures using supplementary cementations materials". *Construction and Building Materials*, 64, 95-102. doi:10.1016/j.conbuildmat.2014.04.033

UR5. Dulaimi, A., Al Nageim, H., Ruddock, F. & Seton, L. (2017) "High performance cold asphalt concrete mixture for binder course using alkali-activated binary blended cementitious filler", *Construction and Building Materials*, vol.141, 160-170. doi: 10.1016/j.conbuildmat.2017.02.155

UR6. Dulaimi, A., Al Nageim, H., Ruddock, F. & Seton, L. (2017), "Performance analysis of a Cold Asphalt Concrete Binder Course Containing High Calcium Fly Ash Utilizing Waste Material". *Journal of Materials in Civil Engineering*. doi: 10.1061/(ASCE)MT.1943-5533.0001883

External Funding (EF)

EF1- KTP 009122, 2013-2015, £217,195 [£125,539 KTP+ £91,656 additional company contribution]. LJMU/Colas KTP project, "Development of a new high value glass fibre reinforced micro-asphalt with high resistance to cracking and deformation".

EF2- KTP 010900, 2017-2020, £146,760 LJMU/Colas KTP project, "Development of a new 'Nano' emulsion with at least two seasonal grades".

Patent (PT)

PT1- GB9818758 A19980827. Granted 2001, "Coated aggregates for use in construction and methods of making the same". Inventor Hassan Al Nageim.

PT2- EP99302141 A19990319, Granted 2006, "A particulate material for use in constructions and method of making the same." Inventor Hassan al Nageim.

4. Details of the impact

The impact has been through: (i) the development and commercialisation of a product (COLBIFIBRE) in the UK and EU, with annual sales of over 7m EU in 2018 and 2019, and (ii) the development of another novel product (Colbond 50X Emulsion), which has recently gone into production.

(i) Sale of products in the UK and EU (COLBIFIBRE)

LJMU's previous research involving experimentation with different waste streams to formulate new cold bituminous emulsion mixtures (CBEM)(UR1), comparing the mechanical strengths between these new mixes along with the traditional HMA methods (UR2) and then comparing different waste streams to improve the curing times of CMA (UR3) resulted in Colas Ltd collaborating in a Knowledge Transfer Partnership (KTP) with LJMU (EF1). The compound COLBIFIBRE was developed through this KTP 2013-2015, where the exact mix of the compound is commercially sensitive and belongs to Colas Ltd.

COLBIFIBRE improves the durability of existing asphalt, allowing the aging stock of roads and highways to remain in service for longer. In addition, it provides a construction environment that is more cost effective and produces no CO_2 during its production and construction, as it is bonded using cold bituminous emulsions.

> *"In 2015, the research results on fibre reinforced micro asphalt were presented to Colas Ltd who partnered with LJMU to perform on-site trials in Leeds and assess its performance. Subsequently, Colas decided to commercialise the product and use it in a number of their road surfacing contracts for Local Authorities in the UK on roads and city streets. In France, the technology has been used in the development of a combined*

> *surface treatment called COLBIFIBRE, with applications on highways/roads ranging from traffic categories T5 to T1."* (EV2)
>
> *"In 2018, the revenue for COLBIFIBRE was about 4m Euros, accounting for resurfacing of more than 500,000 m2 of roads. The sales in 2019 dropped to over 3m Euros, due to difficult trading conditions, accounting for more than 350,000 m2 of roads, and sales indicate similar trade in the first half of 2020, before activity recovers."* (EV3)

The local councils in the UK, France, and Ireland prefer this material application as a maintenance surface layer over other types of road surface layers such as hot rolled asphalt, dense bitumen macadam and mastic asphalt to treat road surface aging.

> *"In France, it is used when pavement degradation is too severe to be treated with other single types of treatment and it restores impermeability to the road surface, improves skid resistance of the surface course, and extends the service life."* (EV2)

None of the conventional micro-asphalts possess the unique characteristics of this product, which include reinforced anti-cracking complex micro-asphalt; dual fibre reinforcement and dual asphalt coating to block cracks; reinforcement of the new wearing course; waterproofing the pavements; and repair of affected areas in a single day. Thin layers postpone major repairs for several years and are suitable for all types of roads. (EV1)

(ii) New product development (Colbond 50X Emulsion)

This new emulsion was developed through a second KTP (EF2) for Colas Ltd in 2019. The emulsion is the first of its kind internationally and emerged through defined industrial needs. Colas required a product to achieve improved bonding strength for a bonding coat applied between pavement layers, which when applied would be able to penetrate dust on the surface and also when fully broken would prevent 'pick-up' on wheels, tracks or tyres of the paver/delivery vehicles. (EV4, EV5)

Colbond 50X Emulsion (EV4, EV5) is also a spray application on road surfaces to promote a stronger adhesion between an old road surface and the new bituminous overlay. This new emulsion made its way into production at Colas' Warrington UK Emulsion and Micro-asphalt plant in February 2020.

5. Sources to corroborate the impact

EV1. Colas Production brochure "COLBIFIBRE" sales, 2018.

EV2. Head of Technical Department, Colas Ltd (confirming the direct annual sales figures for COLBIFIBRE in 2018).

EV3. Head of Technical Department, Colas Ltd (confirming the direct annual sales figures for COLBIFIBRE in 2019 and same trend in the first half of 2020).

EV4. Colas Production case study "Colbond 50X Emulsion", 2020

EV5. Associate Director, Colas Ltd (confirming the development of a new emulsion, Colbond 50X, has gone into production and the predicted annual sales figures).