University Alliance
Doctoral Training Alliance

DTA3/COFUND Programme Research Project Proforma

1 – General Information

Project code	SHEN03
Partner University	Sheffield Hallam University
Faculty/School/Department/Research Centres	STA/MERI
First supervisor Please provide name and weblink	Prof Pal Mangat https://www.shu.ac.uk/about-us/our-people/staff-profiles/pal-mangat
Second supervisor Please provide name and weblink	Dr Abhishek Asthana https://www.shu.ac.uk/about-us/our-people/staff-profiles/abhishek-asthana
Third supervisor Please provide name and weblink	Dr Vincenzo Starinieri https://www.shu.ac.uk/about-us/our-people/staff-profiles/vincenzo-starinieri
Fourth (external) supervisor	Anthony W Bolton, Managing Director Organisation: Process Technologies
External/industrial supervisor	As above - Fourth (external) supervisor
Which of the supervisors listed above is an early-career-researcher	Dr Vincenzo Starnieri (Third supervisor).
Contact details for project for informal applicant queries	Prof. Pal Mangat p.s.mangat@shu.ac.uk
DTA Programme	DTA Energy
Project title	Construction waste comminution with low energy microwaves for high value recycling

Co-funded by the Horizon 2020 programme of the European Union

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 801604.

2 – Project Description

Academic Excellence (500 words)	The proposed project on developing microwave energy technology for accelerated comminution of demolished concrete and tarmac road waste will focus on fundamental aspects and effects of microwave heating at high temperatures. It will involve an interdisciplinary approach including the interactions of microwaves with heterogeneous construction materials, energy, thermal effects, material response to differential thermal stresses and chemical changes. It will lay a strong foundation for innovations in the application of microwaves for recycling construction waste and in the application of microwaves for road repairs. The current state-of-the-art lacks the fundamental knowledge which can be provided by interdisciplinary research. This includes investigation of electromagnetic energy, material microstructure and fracture mechanics, chemical characteristics, effects of constituents of heterogeneous materials like concretes and relationships of operating parameters of microwave energy systems with the properties of the comminuted materials. Microwave technology has been used for increasing metal recovery from mineral ores, such as copper and gold. Similarly, microwave treatment reduces the energy requirement for grinding coal and iron ore. Microwave treatment is even more suitable for multiphase materials like concrete and tarmac. They contain particulate phases embedded in a continuous binding matrix. In the case of concrete the binder phase contains water in its pores which facilitates heating with microwaves. The microstructure and moisture state of the tarmac binder (bitumen) is more complex with respect to microwave heating which affects the bitumen by producing a change in the orientation of polar molecules of the dielectric material. This results in internal friction and an increase of the mixture (tarmac) temperature. The efficiency of heating will be optimised by suitable additives (e.g. a ferrous material) which can reflect the microwave radiation and accelerate the temperature increase. Techniques to heat and melt tarmac with microwave energy will be developed. Microwave treatment will utilise the differences in thermal, dielectric and mechanical properties of each phase to create embrittlement and stress gradients that can lead to neat fracture at grain

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	boundaries. Microwaves will induce internal stresses from multiple sources located within the particles in each phase unlike mechanical processes which apply stresses at external contact points. In addition the high temperatures induced by microwaves will breakdown the constituent binders of the concrete and tarmac to their original cementitious and bituminous phases suitable for high value recycling. All these aspects will be investigated in the project.
Aim (400 words)	Aim and hypothesis: To develop microwave technology for energy efficient comminution of concrete and tarmac construction waste by gaining a fundamental understanding of the interactions between the microwave process and physical characteristics (e.g. pore structure) and chemical properties of the of the construction waste materials. Dielectric properties of concrete and tarmac are suitable for microwave heating. However, the physical and chemical differences of the two materials will pose different challenges for microwave heating including the release of gases with tarmac. The dielectric loss coupling of the materials facilitates their heating by electromagnetic waves during microwave heating. The moisture in the pores has higher dielectric properties than the other constituents which upon exposure to the electric field of microwave energy converts into heat via dipole interactions. The dipoles vibrate releasing heat through friction thus accelerating chemical reactions in the material. The internal heating mechanism of microwaves is fundamentally different from conventional methods which are relatively very energy inefficient. Methodology: SHU's microwave facility at AMP and an industry scale microwave machine provided by the external partner UVAMED will be used to conduct experiments on the comminution of waste concrete and tarmac materials. The magnitude and rate of temperature increase, microwave heating parameters such as power and material properties such as dielectric coefficients, volume, constituent phases, chemical composition will be evaluated and correlated to derive guidelines for microwave system design.

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	XRD, XRF, mercury intrusion porosimetry and surface analysis of aggregates will be used for the physical and chemical characterisation of both the original concrete/tarmac wastes and their comminuted aggregates and the matrix phases. Thermocouples and thermal camera will be used to determine temperature distribution and microwave transmission intensity with depth. Analytical models will be developed to predict penetration of radiative energy and the rates of heat and mass transfer, to optimise the sizing of MC equipment. Numerical models in COMSOL Multiphysics will be developed to compare effectiveness and optimise equipment design. Prepare compositions of concrete and tarmac with the recycled materials and determine performance characteristics relative to virgin materials. <u>Innovations:</u> Potential innovations likely to be developed in the post project period are as follows: • Technique for comminution of concrete and tarmac with microwave energy • Microwave systems for comminution of concrete, tarmac • Microwave machine for road repair by applying the technology developed for comminution and melting of asphalt rubble(e.g. rapid pot-hole repair) • High value use of recycled concrete, particularly the reconstituted cementitious material
Strategic Relevance (300 words)	Providing high temperature comminution technology which enables the separation of binder constituents from the waste thereby enabling recycling of high value products. Current mechanical methods do not provide a clear separation of the aggregates and binder. Thus the aggregates produced are of poor quality and categorised as waste suitable for applications where other low cost materials would suffice. Similarly the binder constituents are not released in a sufficiently clean form to turn them into valuable products. For example the reuse of recycled cement from demolished concrete would reduce the high use of energy in cement

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	manufacture and also reduce the high CO2 impact of cement manufacture using virgin limestone. The construction industry in the UK uses 295mT of virgin aggregates per annum and produces 150mT of demolition waste. Only 46mT is recycled as low quality aggregate which ends up as fill (low value application). The market for high value aggregate and the recycled binder material provided by microwave comminution waits to be exploited. The reuse of old asphalt is set to increase rapidly with prediction of 100% usage (http://www.aggbusiness.com/categories/asphalt-plants-equipment-applications/features/recycled-asphalt-market-expands/). Much of the waste asphalt is currently assigned to landfill. According to UK's WRAP programme waste asphalt can be recycled back to hot asphalt. However, traditional heating technology is very energy intensive where microwave technology offers an energy efficient solution. With roads having a life span of 10 - 30 years, there will always be need for replacement and repair work. This process inevitably produces waste tarmac which can be heated for reuse in new road surfaces. • Replacing antiquated methods (e.g. open flame heating) used in concrete structures and tarmac road repair. This will provide both low energy utilisation and health and safety benefits.
Interdisciplinarity and fit with DTA3	• Energy, thermodynamics, phase change (Abhishek) • Material Science (Vincenzo, Pal) • Concrete and Bitumen technology (Vincenzo, Pal) • Civil Engineering (Pal, Dimitra) • Modelling, Optimisation (Abhishek, Dimitra) • Microwave technology (Anthony)
Industrial Relevance (300 words)	• SHU's existing microwave facility at AMP will be enhanced through our existing collaborations with

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	Uvamed Ltd., UK and Process Technologies Ltd., UK **(Letters of support provided from the two companies)**. They will also support new projects to develop the innovations listed in this proposal, starting with comminution processes suitable for industry. They will provide placement opportunity directly or through their industrial networks. The MD (Anthony Bolton) of Process Technologies Ltd. collaborates with the University of Leuven in Belgium in their mutual (complimentary) expertise in microwave technology. • Uvamed will provide an industry scale microwave machine for SHU's AMP facility. They will also provide networking with industry in U.K and Europe. Examples of such networks include Beltiotikes Technologies Monoprosopi EPE, Greece; Jorg Heizmann Bauunternehmung GMBH, Germany; E.R.S. - Steuerungstechnik - GmbH & Co. KG, Germany; UTINGAL SL, Spain. • Our EU funded MCure project which was concerned with microwave curing of concrete (very different to comminution) has also provided other links in the EC which include Fraunhofer and AFT microwave GmbH at Donaustr.
Economic and Societal Impact (300 words)	<u>Economic:</u> • Energy savings in construction process and waste recycling by the use of low energy microwave technology • Creating IP and an industry for microwave machines for the construction waste recycling sector • Rapid energy efficient repairs (e.g. pot-holes in roads) with microwave technology for efficient usage of the transport network e.g. R&D on the development of a rapid pot-hole repair machine is currently being planned with our industrial supporter of this application • High value applications of recycled aggregates and the cement and bituminous binders respectively from waste

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	concrete and tarmac. Development of new businesses to implement the technology. Societal: • Save energy and reduce CO2 impact by using energy efficient technology for comminution of construction waste and producing quality recycled products suitable for high value applications. For example comminution of demolished concrete with microwaves should produce high quality aggregates and cement suitable for recycling. This will reduce the CO2 footprint of the cement industry which currently produces about 8% of the world's carbon dioxide (CO2) emissions, according to think tank Chatham House. There are similar potential benefits from the comminution and recycling of road surface construction waste. • Provide safe working relative to current practice e.g. by developing safer machines for the comminution of construction waste and prevention of open flame heating in tarmac and concrete repair industry • Improve quality of road network leading to safety of cars and passengers by reducing the cost of repair and maintenance of roads.

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3 – Admission Requirements

Specific Admission Requirements	A science or technology graduate with background in Civil or Materials Engineering or a closely related discipline will be suitable for this project. Knowledge of Construction Materials and experience of experimental techniques mentioned above is essential
Minimum IELTS score	An overall IELTS score of 7.0 or above, with at least 6.5 in each component or an accepted equivalent

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