1. Sustainable self-healing polymers for soft robotics

Summary:
Soft robotics is a field focused on studying the use of flexible and compliant materials as components for building robots instead of rigid traditional materials, such as metals. The field of soft robotics is moving really fast in the last years as soft robots are developed with new capacities, materials and designs. In collaboration with the Robotics and multibody mechanics (R&MM) research group, we have developed self-healing robots capable of recovering from damages such as punctures or scratches. These self-healing materials are based on the reversible Diels-alder reaction between a furan and a maleimide functional group. Using this chemistry, we can synthesize materials that can heal severe damages with an efficiency close to 100%. Nevertheless, there is still work to do to bring these materials to commercial applications. In this sense, one of the most urgent matters faced is the improvement of their sustainability and avoiding the usage of dangerous chemicals.

The main objective of this thesis will be to explore new bio-based and sustainable raw materials, such as the ones shown in Figure 1B, to substitute the current materials used for the self-healing polymers. Promising results have been already obtained using oil extracted from castor seeds. The student will contribute to the optimization and development of this material. Nevertheless, motivated students are encouraged to propose their own approaches, the viability of which will be evaluated before the starting of the thesis.

Figure 1 A) Self-healing soft pneumatic hand demonstrator build using Diels-Alder polymers. B) Some examples of bio-based sources that can be used in the synthesis of polymers.

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Summary:
The effect of the addition of electrically conductive nanomaterials (carbon black, graphene, CNT) to reversible polymer networks (RPN) was studied in previous work. The electrical conductivity threshold was determined and the effect on the viscoelastic and mechanical properties, thermal transitions and the self-healing behaviour of the RPN was evaluated. It was shown that at filler loadings high enough to obtain stable electrical properties, the flexibility of the composite and the mobility required for successful healing decreased considerably. In this work, the efforts will be made to obtain excellent electrical conductivity, while retaining the flexibility and mobility of the composite matrix as much as possible. This is crucial for the development of self-healing conductive materials for flexible electronic devices, such as sensors.

Sensor designs will be created by combining conductive and non-conductive RPN or by directly incorporating them in the design of soft robotic actuators, to assess the feasibility of tracking movement and deformation of the actuator and sensing damage. The focus of this project will be on the material design, development, production and characterization and the fabrication of sensors. This project is performed in parallel to a master thesis project at the R&MM group for validation towards applications for strain and damage sensors and self-healing assessment in robotic actuators.

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3. Design of a low-cost prosthetic liner for developing countries

Summary:
An estimated 40 million people living in developing countries need a prosthetic. Millions of these amputees live in central Africa, while only about 5-15% of these patients receive a prosthetic limb. Ugani Prosthetics is a social entrepreneurship that wants to tackle this scalability issue. 3D printers and 3D models have been around for many years, but they don’t seem to get to the people who need them the most. Ugani Prosthetics’ goal is to create impact on a large scale, by quickly expanding local manufacturing capabilities, and expanding to different cities and countries with a proven business model.

As you can see from the images below, we already have a design for a socket that is slightly adaptable to change together with the leg throughout the day. Inside of this socket, the patient needs to wear a liner, which is a sort of sock that fits around the stump. Today, liners are made out of silicone, thermoplastic elastomers, urethane or other soft materials. They drastically increase the comfort of the patients as they reduce friction and wounds on the stump. They can cost several hundreds of euros, meaning that they double the cost of our prosthetics.

As the liner is a vital part of every prosthetic, the goal of this master thesis is to improve the existing designs. New materials and production techniques have to be researched, just as new and better designs. Alternatives like cushions in the socket are also a possibility. The liner should be low cost, comfortable, easy to produce and durable. Additionally, it should reduce sweating as our patients live in a hot and humid climate and transpiration can cause irritation of the skin.
This project is in collaboration with a mechanical engineering master thesis student at the Robotics & Multibody Mechanics research group of the Mechanical Engineering department and with Ugani Prosthetics.

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4. Multi-material additive manufacturing of self-healing for soft robotics and flexible sensors

Summary:
Soft robotics is a young field of robotics with a focus on the use of flexible materials to build robots for safer interaction with humans and other soft objects. The Physical Chemistry and Polymer Science (FYSC) and the Robotics and Multibody Mechanics (R&MM) research groups have developed self-healing soft robots which can fully recover their shape and mechanical properties after damages like cuts and punctures. These self-healing materials are based reversible covalent polymer networks using the Diels-Alder reaction to form reversible crosslinks. The reversibility of this bond is temperature controlled and for this reason these materials can be processed using additive manufacturing techniques such 3D printing.

The main objective of this thesis will be to work on the adaptation of the viscoelastic properties of the self-healing materials and the optimization of the 3D printing process conditions, in particular for fused filament fabrication (FFF). In the past, a soft robotic gripper was printed out of a single material. The goal now is to be able to print more complex shapes that can improve the robot performance. The main challenge is to obtain a smooth filament to improve the quality of the surface finish.

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5. Advanced reversible covalent polymer network design for improved stimuli-responsive properties

Summary:
Reversible covalent polymer networks offer a number of advantages compared to permanently crosslinked polymer networks, such as reprocessability and self-healing. Reprocessability is important for the end of life of these materials, while the ability to repair damage can drastically extend the service lifetime of materials in certain applications. However, similar to thermoplastic elastomers, these reversible networks also suffer a trade-off between their mechanical properties and the mobility and reversibility required for self-healing and reprocessing. The aim of this thesis is to adjust the polymer network architecture of the reversible covalent networks to achieve high mechanical properties, while retaining excellent self-healing behaviour. The network composition will be altered by (1) evaluating different reversible covalent chemistries, (2) the choice of the monomer building blocks, (3) their functionalization and (4) their judicious combination to create networks with varying viscoelastic properties and stimuli-responsive behaviour.
The mechanical properties will be evaluated in applications with strict mechanical property requirements, such as soft robotics. High ultimate strength, fast elastic response and excellent cyclability are primary requirements for such mechanical structures. In collaboration with the Robotics & Multibody Mechanics (R&MM) research group, the materials will be subjected to many types of complex, dynamic deformations in a controlled fashion using tensile, compressive and bending modes. Finally, the materials will be processed into a robotic actuator for experimental validation.

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6. Cement recovery by microwave heating: product valorization  
Summary:  
Recycling of cement from old concrete could substantially reduce CO₂-emissions. MW technology is a promising energy-saving tool for the recovery of cement, with much lower CO₂ emissions (use of electricity instead of burning fossil fuels). After MW heating between 400°C and 800°C, efficient dehydration of hydrated cement phases in concrete waste occurs, converting ‘old’ cement into a high-value low-carbon recycled binder that can (partially) replace Portland cement or that can be used as slag-activator in concrete. This thesis aims to investigate the reactivity and cementitious capacities of different recycled binder mixtures (MW-treated recycled cement – Portland cement – blast furnace slag). Variables that will be assessed include: dehydration temperature of MW-treatment, milling parameters (finer powder will be more reactive), different mix ratios, the use of a setting time retarder, etc. The key task will be to experimentally determine reactivities (calorimetry) and mechanical properties (compression tests) of various recycled binder mixtures. The project is in combination with industry for the microwaving part.

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7. Thermal stability of inorganic polymers from copper slag: use as construction material in high temperature applications  
Summary:  
Copper slag remains an industrial waste with a large unutilized fraction. Previous studies have shown that it is possible to use these residues as aluminosilicate precursors in alkali activated materials, as an environmental alternative to cement. However, little is reported on the thermal stability of alkali activated copper slag, especially at high temperatures. The present project aims to investigate this for potential high temperature applications. The effect of thermally stable additives such as calcined bauxite or metakaolin will also be investigated. Potassium silicate solutions will be used as alkaline reagent. Mortars will be prepared and their composition will be optimized. The prepared materials will be characterised by several technics including a newly developed technique (our lab in collaboration with industry) to monitor the Elastic modulus on heating/cooling, TG/DTA, residual compressive strength.

Key words: copper slag, alkali activated materials; thermal stability; calcined bauxite; metakaolin

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8. Fiber reinforced cementitious composites  
Summary:  
Most fibre reinforced composites today have a thermoset matrix. A drawback is their poor thermal resistance while they are also harmful to the environment. To reduce the environmental impact, inorganic polymers – cements- could substitute the thermosets. Another advantage is that these cements do not emit dangerous substances, and cleaning can be done with water, rather than with solvents. In this subject, you will focus on a new kind of alternative cementitious composite. In addition, it was found that some solid waste, like Koranel® from industries can be used as a reactant or filler in the cement to improve the mechanical properties of the laminate. Optimization of matrix workability, suitable fiber selection (C-fibre, alumina fibre,...) as well as optimal fiber volume fraction in the laminates will be done in this subject. Because it is a novel material, a
strategic selection will be applied in the frame of this project by combinations of matrix recipes and fiber constructions. The project is in collaboration with industry where the production of the composites will be upscaled.

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**9. Ecological cements from metallurgical residues – Reactivity assessment**

**Summary:**
Metallurgical slags have a great potential for being recovered and valorised as “green” building materials. In order to check the potential of different slags to be used as alternative cements, several techniques are being used to assess their reactivity.

This will be done by a combination of techniques, namely: dissolution and isothermal conduction calorimetry. In the first set-up, the materials are milled to the same particle size and mixed with NaOH or Na-silicate, in polypropylene bottles, followed by shaking, filtering, and measuring the dissolved Si, Al, and Fe in the liquid phase. In the second set-up, the same materials are mixed again with alkalis, but are now recorded for their heat evolution.

From the slags having the most interesting compositions, samples will be prepared, and their compressive strength will be measured.

This work is part of an Era-MIN European project, the described experiments will be made in collaboration with University of Aveiro, Portugal.

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**10. Explorative study of self-healing powder coatings**

**Summary:**
Traditionally, powder coatings are applied by heating up thermoplastic or thermosetting particles to induce flow, and eventually to cure (i.e. crosslink) the material in the case of thermosets. In the latter case, this results in processing temperatures above 150 °C, unsuitable for heat sensitive substrates (e.g. wood). In this master thesis, the feasibility of self-healing powder coatings based on reversible Diels-Alder (DA) bonds will be investigated. The working hypothesis is that by using such materials, flow at high temperatures (= breaking of the reversible bonds) can be decoupled from cure at lower temperatures (= formation of the reversible bonds) enabling a coating process at lower temperatures than traditional thermoset powder coatings, which is crucial for heat sensitive substrates. The following will be explored: rheometric study of flow, dynamic mechanical analysis (DMA) of cure during cooling, study of thermo-mechanical stability and upper temperature limitations, role of side reactions, ...

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**11. Advanced thermal characterization of materials for organic photovoltaics and/or NIR photodetectors**

**Summary:**
Solution-processable organic photovoltaics (OPV) and photodetectors (OPD) have gained ever-increasing attention due to advantages over their inorganic counterparts, such as printability, flexibility, light weight, and low cost. The final morphology will greatly influence the performance and stability of a device. A thorough characterization of such materials (polymers or small molecules) is therefore required to gain insight into the phase behaviour, and link this to device performance. FYSC has extensive experience in the characterization of OPV materials by advanced thermal analysis (e.g. rapid heat/cool DSC and chip calorimetry) and complementary techniques (e.g. SEM, AFM, etc.). While the research will take place in FYSC, it is part of a collaboration with research groups at Hasselt University, who are specialized in synthesis of novel materials and device manufacture. This subject will make students familiar with the exciting and quite recent field of organic electronics, and their study by advanced thermal analysis techniques.

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12. Thermal degradation of polyurethane foams – linking structure and fire behaviour

Summary:
While polyurethanes (PUR) are often used in fields where thermal stability, fire resistance and flame retardancy are important, like construction materials, furniture and textiles, their degradation mechanisms and kinetics are poorly understood. The main goal of this project is to develop a generic kinetic model linking the thermal stability and thermal degradation behaviour to the chemical structure of the PUR. Insights in the structure-reactivity relationships will allow for predicting the thermal stability at different temperatures and atmospheric conditions based on the composition. The thermal degradation of a series of PUR with different compositions will be tested in air and in N₂ using TGA combined with MS, while FTIR and NMR will be used to analyse the remaining decomposition products. Thus, we will couple the kinetics of the degradation process with the chemical and structural changes in the networks.

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13. Frontal Polymerization

Summary:
Frontal polymerization is a method of rapidly converting monomer to polymer through the propagation of a localized reaction wave. It is an energy-efficient way to produce high-$T_g$ thermosets, but also finds applications for elastomers and hydrogels. In frontal polymerization, a small energy input in one point initiates the reaction, which through its exothermicity and its acceleration with increasing temperature leads to the generation of a reaction wave, rapidly progressing through an entire mould or coating and turning the liquid monomer into a rigid polymer. In this project, we want to study the effect of heat losses on the stability of polymerization fronts. This will involve both experimental work (designing test setup, studying polymerization kinetics) and heat transfer and reaction modelling.

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Physical Chemistry and Polymer Science (FYSC) – Electrochemical and Surface Engineering (SURF)
Department of Materials Science and Chemistry (MACH)

14. Investigating the barrier properties of coatings by thermal and surface analysis techniques

Summary:
Coating technology provides surface protection, decorative finishes, and numerous special functions. The daily use of many everyday products depends critically on their surface treatment. Take cars for example: the metal body provides the desired mechanical properties, but it needs to be coated for a long-lasting service. In general, whether in automotive or construction industry, protecting metallic surfaces against corrosive environments is the main application of high performance coatings. The metal/coating interface, and the bulk of the coating are interconnecting subsystems, co-dependently contributing to the protection performance. Improving the protective properties of this system requires understanding of the physical and chemical processes defining the service life of the coating in practice. The objective of this study is to understand these processes through advanced coating and surface characterization, and to control them through the identification of the effective parameters.

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