ANNEX B. STUDY DESCRIPTION

Durable polymer textile material as a host for reversible dioxygen-binding metal complexes for the use in space applications

Study reference number: 16-9401
Type of activity: Standard Activity (30k€)

Project Summary

Objective

This project will study the design of a polymeric textile as a host for a metal complex able to reversibly bind oxygen.

Target university partner competences

Oxygen Sensors, Reversible and Selective Chemisorption, Inorganic/ Coordination Chemistry

ACT provided competences

Space architecture, textile technology, polymer chemistry

Keywords

Oxygen, reversible binding, textile, spacecraft, space habitat

Study Objective

This study aims at investigating an oxygen absorbing and releasing polymeric textile material in view of its potential use in space as a low mass and reliable substitute or addition for oxygen tanks. Other ideas for the use of the polymeric material are investigated. The overall idea is to develop a textile material which is able to reversible bind, not only oxygen, but also nitrogen, and remove carbon dioxide from the air. However, the binding of nitrogen and carbon dioxide are out of the scope of the current proposal and will be investigated in the future projects.

Background and Study Motivation

The project focuses on the design of a polymer that acts as a host for metal complexes that are known to reversibly bind and release oxygen. It has recently been demonstrated that a Co-complex, which reversibly binds and releases oxygen at high quantities, can be fabricated. The authors state that the complex stores oxygen at levels 32 times greater than O_2 gas at 1 atm and 160 times greater than air. The material will absorb 99 % of O_2 from the air at room temperature [1]. The current standard approach to storing oxygen for human space missions are oxygen tanks. On the International Space Station (ISS), the oxygen partial pressure is maintained at a range of 2.82 – 3.44 psi and the total pressure is maintained between 14.0 – 14.9 psi [2]. Oxygen partial pressures are maintained primarily by electrolysis of water and is supplemented with represses from stored resources as necessary. Oxygen on the ISS is primarily generated by electrolysis. One system that is used is the USOS Oxygen Generator Assembly electrolysis unit. Supporting a crew of six astronauts, it produces 0.20 kg/day and 9.25 kg/day of oxygen in standby and in 100 % production mode, respectively. A resupply of the ISS with the Automated Transfer Vehicle (ATV) brings 100 kg of oxygen in high pressure tanks (Recharge Tank Assemblies, RTAs). The RTAs contain 48.263 kPa oxygen with a volume of 0.076 m^3 and a weight of 38.1 kg oxygen.

In addition to binding and releasing oxygen, the textile material could also fulfil other functions in space applications. In space habitats and spacecrafts the textile could be used as an interior layer to the structural shell, which would act as an additional reinforcement by distributing the forces caused by the differential pressure along the shell surface. It would also be possible to use the material as an acoustic blanket to deal with a sound pollution in noisy environments. In habitats, the textile could serve as an oxygen transport mechanism from a greenhouse, where the oxygen is produced, back to the habitat. The use of such a material would decrease the volume, mass and power consumption of an Environmental Control and Life Support System (ECLSS) used in the habitats and spacecrafts.
The material could also be used as an oxygen mask, or as an inner lining in Extravehicular Mobility Unit (EMU) and rovers in order to support or replace the oxygen tanks. Due to the malleability and low weight of the material it could easily be applied to any complex structure.
The material could also be used as a sensor for measuring the O2 level in habitats, spacecrafts, EMU or in any other suitable application.

A metal complex with similar or higher performance than in [1] with regard to oxygen release and uptake is to be proposed and prepared by the candidates. Hereby, the rate and reversibility of oxygen sorption are important factors, as well as the trigger used to release or bind the gas. Ideally, the complex responds to changes in the oxygen level of the surrounding. Two approaches seem possible to insert the metal complexes into polymer networks, but other approaches proposed by the applicants are welcome:

1. The metal complex itself is functionalised with polymerisable double bonds. The ligand is thus polymerisable and can be co-polymerised with the main monomer, which requires the metal complexes to be resistant to the polymerisation conditions (typical aramid polymerisation is performed via polycondensation at 0 °C in an amide solvent and using alkali earth metal salts as solubility promoter) [3,4].

2. The metal complex is mixed with the polymer solution during the filament formation procedure, e.g. wet spinning or dry spinning. It has to be ensured that the metal complexes are resistant to the elevated temperatures of an extrusion

process of around 100°C (wet spinning) [5] and around 100°C - 350°C (dry spinning) [6]. The temperature range during the additional heat treatment after the extrusion (if necessary) process could be from 200°C (dry spun) or from 360°C to about 550°C (wet spun) [5]. In addition to the high temperatures and pressure, the metal complexes need to resist the high tension during the drawing process and heat treatment. The tension in these processes varies a lot due to being dependent on the desired final yarn properties.

The general requirements for the materials used in space applications are as follows:

- Sufficient shelf life/ life cycle
- Resistance to space environment (UV/ thermal/ radiation/ abrasion/ vacuum/ meteorite impacts)
- Resistance to fatigue (acoustic and machine vibration/ pressurization/ thermal/ deployment)
- Resistance to stresses (launch loads/ pressurization/ impact)
- Resistance to penetration (meteoroids/ mechanical impacts)
- Biological/ chemical inertness
- Reparability

Aramid is one of the high-performance polymers used in aerospace applications due to its high strength and low weight properties, as well as for its resistance to abrasion and chemicals. One of its main advantages over the other high-performance fibres is its low-flammability property, which makes it a safe fibre to use in the interior spaces of aerospace applications. The polymer-metal hybrid material could be spun into a yarn which then would be woven or knitted into a textile for the use in space habitats, space suits etc. as a support or replacement for the oxygen tanks. The design of the structure of the yarns is crucial in enabling the oxygen binding and release. The weave or knit structure needs to be designed in a way to maximise the binding and release of oxygen, and to minimise the weight. The properties (e.g. tensile strength, weight, flammability, density, etc.) of the yarn and textile need to be confirmed.

Aramid is a good candidate for fibres used in space applications, when not exposed to direct UV radiation, due to the following properties [7]:

- High strength, high modulus
- Light weight
- Resistance to abrasion and impact
- Resistance to organic solvent, good chemical resistance

- No conductivity
- No melting point
- Flame retardant
- Excellent heat, and cut resistance
- Dimensional stability
- Malleable
- Corrosion resistance
- But sensitive to acids and ultraviolet radiation

The colour of the material depends on the type of polymer used, as well as on the saturation level of oxygen in the polymer, and can thus be easily monitored.

Proposed Methodology

The following methodology is proposed for the study, though applicants are invited to propose different approaches which they see fitting better within the scope of this work.

- Assess the suitability of a metal-complex to reversibly bind and release oxygen via theoretical/ experimental analysis and derive:
    - Sorption rates, influence of temperature and pressure, selectivity towards oxygen
- Ability and stability of the metal complex to be incorporated into a space-durable polymer by polymerisation (thermal stability, functionality, repeatability)
- Assess the amount and duration of O_2 bound and released in the material
- Conduct an elemental analysis
- Parametric study comparing different use cases (habitats, deep space, surface, EVA suits, etc.)
- Test the final material product on a yarn and fabric level (possibly a follow-up study):
    - Yarn testing:

    a. Standard

    1. Linear density
    2. Evenness
    3. Friction
    4. Breaking strength/ Tensile strength
    5. Tenacity
    6. Young's modulus

7. Elastic recovery

b. Space environment

1. UV sensitivity
2. Radiation resistance
3. Outgassing
4. Thermal stability

- Fabric testing:

a. Standard

1. Fabric strength
2. Tearing strength
3. Stretch and recovery properties
4. Dimensional stability (hygral expansion, relaxation shrinkage, swelling shrinkage, felting shrinkage)
5. Serviceability (snagging, abrasion resistance)
6. Thermal conductivity
7. Moisture absorption
8. Flammability
9. Handle (stiffness, shear, friction)

ACT Contribution

The project will be conducted in close scientific collaboration with ESA researchers. In particular ESA researchers will provide technical expertise in polymer chemistry and textile technology, and space system engineering expertise especially for the suitability of such polymers for human spaceflight missions. The polymer is intended to be spun into yarns and woven or knitted into a high-performance textile for space applications.

Bibliography

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