Final Report Summary - OXIGEN (Oxide Dispersion Strengthened Materials for the Additive Manufacture of High Temperature Components in Power Generation)

Executive Summary:
The concept of OXIGEN is to achieve increased efficiencies (>30%) in power generation by enabling higher operating temperatures of gas and steam turbines. This will be achieved by the development of Oxide dispersion strengthened alloys, a class of materials that offer exceptional high temperature strength, oxidation and corrosion resistance at high temperatures exceeding 1000ºC. While the fundamental material properties of ODS alloys are exceptionally well suited to power generation, the manufacture of components using ODS alloys are currently subject to a number of economic and technical barriers.
including (1) no means of efficient powder production (2) low volume supply chain, (3) difficult to process and (4) coarse grain size can give variability in creep.

The main thrust of ‘OXIGEN’ was the development of optimised materials for high temperature operation of SLM and LMD manufactured parts. WP2 extended that thrust and provided “significant added value” by demonstrating capabilities to generate additional functionality and intelligence in the form of in-situ condition monitoring at very high temperatures in components manufactured utilising the unique opportunities offered through the layer by layer build processes of SLM and LMD additive manufacturing technologies.

WP2: Fibre optic sensors, capable of operating at temperatures in excess of 800°C were developed, and embedded into components as part of the SLM/LMD manufacturing process, providing structural and condition information from within a part. In order to achieve these goals, in-fibre Fabry-Perot type sensors temperature sensors were developed and tested up to 1000°C, fibre Bragg grating based strain sensors were embedded as an integral part of a SLM manufactured part and permit in-situ strain monitoring up to 800°C, far in excess of previously attained temperatures. The detailed understanding of the behaviour and stability of fibre sensors under high temperatures and the challenges of processing fibre material for use at these conditions went beyond state of the art and have been published and presented in peer reviewed journals and conferences. Many of the individual R&D findings leading up to these capabilities represent individual key achievements significantly beyond the state of the art. Embedded strain sensors can for example also be used for process monitoring in the SLM manufacturing process per se, assisting in process optimisation, reduction of stress in parts.

Although WP2 had no direct interface with our eastern European partners, the positive experiences of working and interacting with these partners in the project were a very positive element and contacts formed will be utilised for dissemination into new geographical areas.

WP3: was concerned with the selection and development of Oxide Dispersion Strengthened (ODS) alloys for the project, and their subsequent testing. In conjunction with our end users, two existing Ni-based alloys and one new Ti-Al-Nb alloy type were eventually selected for ODS addition and processing. Phase diagrams were modelled for all the alloys selected and the effects of small additions of Y and Hf, which might be incorporated via ODS particles, were investigated. No new detrimental phases were predicted, but it was found that Hf could depress the solidus temperatures. Phase fractions in Ti-Al-Nb alloy were also very sensitive to Al content. We successfully demonstrated that yttria based particles could be incorporated into powders of all the selected alloys by mechanical alloying, although the use of nm sized yttria additions was shown to give much improved homogeneity and distribution of oxide particles after mechanical alloying.

The addition of ODS particles to a new Ti-45Al-3Nb alloy led to grain refinement, grain boundary pinning and enhanced mechanical properties over a wide range of temperatures, with little segregation after SLM or LMD processing; and the alloy had lower weight gain and good scale adherence when oxidised at 650°C when compared with existing commercial alloys. Cracking on cooling could be minimised by use of a heated substrate and slow cooling during LMD processing. ODS additions to IN625 gave x40 improvement in oxidation resistance compared with the non-ODS variant; while prolonged high temperature testing produced little coarsening of oxide dispersoids. Excellent samples of ODS IN625 and
ODS H230 could be fabricated by SPS but it proved difficult to optimise build parameters for SLM and LMD to give uniform, defect-free samples. The new ODS variant of a Ti-Al-Nb alloy is now being fabricated into components for turbines, while the ODS variant of IN625 is a promising addition to the existing range of high temperature superalloys for use in high temperature turbines.

WP4: powder manufacturing routes based on mechanical alloying have been developed, optimized and scaled-up for Ti-based and Ni-based ODS alloys for Additive Manufacturing. Characterization and quality control procedures have been implemented to verify the achievement of microstructural and morphological requirements.

Homogeneous dispersion of nano-oxides in metallic matrix has been obtained by an efficient solid state process based on High Energy Ball Milling (HEBM). Additional procedures for size and shape control and for alloy annealing have been implemented, allowing to select the most suitable particle size distribution and microstructure for both LMD and SLM techniques.

The efficiency of powder manufacturing cycle has been improved by refining process conditions and by integrating the recycling of unused fractions, allowing to increase the process yield in addressed Particle Size Distribution (PSD). This, together with an accurate selection of raw materials, led to competitive projected costs for the resulting powder, compared to conventional non-ODS powders available in the market.

The outcomes of Oxigen project have a relevant exploitation potential for MBN and Matres, with the possibility of commercialization of ODS and non ODS TiAl-based alloys for AM and of further development and customization of Ni-based ODS powders.

WP5:
Selective laser melting, laser metal deposition and conventional sintering techniques were used to validate the manufacture of test specimens using the ODS powder developed in WP3 and manufactured in WP4. For LMD success was achieved in the deposition of TiAl materials giving a 2 fold increased in corrosion resistance. Mechanical alloyed powders were also successfully processed using SLM but those alloys with inclusion of ODS particles proved more problematic from a thermomechanical viewpoint. This was somewhat overcome by adopting a blended approach to ODS inclusion which gave material benefits but with a reduced number of oxide particles remaining in the matrix.

WP6:
WP6 was concerned with technology demonstration and validation in the framework of the OXIGEN project. The project scope was to develop materials that allow operation of power plants at high temperatures as well as materials and methods for high temperature structural monitoring, all in order to increase efficiency, reduce emissions and increase reliability. All of these goals were met to a certain extent as could be shown during this phase of technology demonstration and validation.

In WP6 demonstrators were built from 4 different materials or material combinations. These materials were Haynes 230, IN625-ODS, TiAl and TiAl-ODS applied on the following demonstrators: Burner Segment, Turbine Blade Coupon, Turbine Blade and Heat Shield.

Along with the making of the demonstrators from SLM and LMD, test specimens were produced as well and further tasks were performed such as cutting, machining, polishing, optical measurements, roughness
measurements, sensor integration, CT scanning and heat treatment.

WP6 was subdivided into 10 tasks. The first task was preparational where sufficient amounts of ODS powder materials for manufacturing of the demonstrator parts as well as all test specimens were supplied by MBN (mechanically alloyed TiAl-ODS) and by Inspire (blended IN625-ODS). SLM and LMD build strategies were finalized by Inspire and TWI to obtain the best results possible from manufacturing. HWU prepared all final tools and strategies for implementing sensors into the demonstrator parts. All end users (GE, Ivchenko, Siemens) prepared the 3D CAD files required for manufacturing.

The second, third and fourth task comprised the manufacturing of all demonstrators using SLM, LMD and hybrid approaches. The fifth task was concerned with embedment of fibre optic sensors and their respective testing while the sixth task took care of all post-machining and metrology issues.

The seventh task was the NDT validation and QA of the specimens also produced in tasks 2, 3 and 4. The tasks 8, 9 and 10 demonstrated performance benchmarking, powder production capabilities and life cycle impact.

Project Context and Objectives:
The concept of OXIGEN is to achieve increased efficiencies (>30%) in power generation by enabling higher operating temperatures of gas and steam turbines. This will be achieved by the development of Oxide dispersion strengthened alloys, a class of materials that offer exceptional high temperature strength, oxidation and corrosion resistance at high temperatures exceeding 1000ºC. While the fundamental material properties of ODS alloys are exceptionally well suited to power generation, the manufacture of components using ODS alloys are currently subject to a number of economic and technical barriers:

• Currently available mechanical alloying processing equipment for production of ODS alloys are time consuming and not effective, leading to high production cost.
• Low volume supply chain lacks major industrial producers i.e. Special Metals and Plansee have stopped ODS production.
• Oxide particle coarsening using conventional fusion (high heat input) joining techniques can lead to reduced high temperature creep strength.
• Difficult to repair for reasons given above.
• Difficult to manufacture with traditional machining techniques (drilling, milling, grinding) due to their superior properties.
• Superior high temperature creep strength in an ODS material requires recrystallization which produces coarse, usually high anisotropic grain structure.
• Coarse grained ODS alloys can give significant component to component variability in creep life.

Moreover, these alloys tend to be creep brittle (e.g. <1% creep elongation to failure), so there can be little warning of imminent failure using time averaging approaches, increasing the risk of unplanned downtime.

OXIGEN will address the limitations given above for existing ODS alloys, focusing on the manufacturing of gas and steam turbine engine components for power generators. To achieve this, OXIGEN proposes to undertake development in four areas; (1) Development of new ODS powder materials, (2) Development of ODS powder production techniques, (3) Development of flexible and efficient powder-based additive
These four development areas will be combined within OXIGEN to enable the end-users (generator manufacturers) to be able to select components, and; improve their high-temperature performance (based on new ODS materials), optimise their design (based on new flexible AM manufacture) and embed sensors/features. The project will also compare the ODS materials developed and AM manufacturing to traditional materials and conventional powder metallurgy processes (sintering, HIPing). This will allow simple selection of the most cost-effective methods for production of higher efficiency generators. Each of these development areas will also consider comparisons with more common material classes for the purposes of benchmarking and knowledge based design opportunities.

The OXIGEN consortium represents the two largest European-based power generation turbines manufacturers (SIEMENS and ALSTOM); who represent ~30% of world-wide orders for gas and steam turbines. In addition, IVCHENKO represent approximately 70% of gas and steam turbines (and compressors) in Ukraine and significant reach in Eastern Europe, Russia and India and will seek to introduce new turbine components to Eastern Europe (see Figure 2a).

These end-users will look to apply the results of the OXIGEN project approach to improve the performance and efficiency of their next generation gas and steam turbine. A number of suggested ‘demonstrator’ parts have been identified by SIEMENS, ALSTOM and IVCHENKO and described as part of WP1 deliverable.

The OXIGEN project is focussed on achieving six key objectives:

1. Project Specification: To identify existing components and detail required materials performance to enable higher working temperature; define required materials performance targets and identify target ODS materials and alloys.

2. Materials Development, Modelling and Screening: To develop high performance alloys that will compete with existing high temperature performing materials; Develop materials to achieve performance targets, as defined in Objective 1 above.

3. Powder Material Production, Characterisation and Optimisation: To develop equipment and procedures to produce powder alloys from material grades developed within OXIGEN

4. Procedures Development and Test Specimen Manufacture: To develop procedures using ODS powders to manufacture demonstrator parts for validation in increased turbine efficiency.

5. Sensor Design, Development and Integration: To develop and embed fibre sensing technology for in-service monitoring of optimised components; develop Fibre Bragg Gratings (FBG) to facilitate high temperature strain sensing arrays capable of continuous in-service monitoring for stress corrosion cracking.
6. Demonstrator Manufacture and Validation: To produce at least 3 components/optimised components, some with integral sensors, for performance testing and monitoring by end-users; achieve up to a 30% increase in engine efficiency by operating with exhaust temperatures above 615 °C.

The impacts include:
1. Increased power plant efficiency by at least 30% allowing operations at substantially higher temperatures
2. Lower, cost efficient emissions (e.g. CO2 and/or other pollutants)
3. Improved Reliability of in-service materials
4. Increased safety in the plants of application
5. Boosted cooperation between the EU and the Eastern partnership countries.

To achieve the OXIGEN key objectives the work is divided into six technical work packages, five will involve high technology research and development and one will encapsulate all demonstration activity. A further two work packages, Project Management and Dissemination and Exploitation, will support the technical activity.

Project Results:
The overall work plan strategy for the OXIGEN project has been defined in the Pert diagram (see Figure 4a). There are 3 phases to the project: (1) Demonstrator Road-mapping (component, materials and technologies specifications), (2) technology, material and procedures development for component manufacture and (3) demonstration, testing and validation (relevant demonstrator applications manufactured using ODS alloys).

(see Figure 4a: OXIGEN Pert Chart in the attachments)

Potential Impact:
5.1 Project Impact

Within the project duration 20 publications have been published:

• OXIGEN project website,
• 10 conferences,
• 1 conference poster,
• 2 abstract,
• Journals,
• 2 PhD Thesis,
• 1 IP application has been submitted → publication planned on or shortly after 29 June 2018.

Currently further 9 publications are planned for 2017ff.

5.1 Website

The project website is available at http://www.oxigen-project.eu/. It allows the public dissemination of the OXIGEN programme and the controlled exchange of documents between beneficiaries via a secure login page.
5.2 Journal articles
The publication of research articles is essential for academic beneficiaries and R&D departments of industrial beneficiaries as this primarily contributes to the impartial evaluation of the research work.

The list of the published and submitted papers sorted by release date is tabulated in appendix A1.

5.3 Conference participations
Conference participations included preferential oral presentations, poster presentations, and proceedings. Many conference papers were reviewed according to conference regulations. All of the OXIGEN beneficiaries are main authors regarding the scientific and technical themes addressed in the conference.

The list of dissemination activities generated by the OXIGEN project is tabulated in Template A2.

List of Websites:
http://www.oxigen-project.eu/

Dr Carl Hauser, Principal Project Leader, Yorkshire Laser Additive Manufacture Electron Beam, Friction and Laser Processes Group (EFL) TWI. Technology Centre (Yorkshire) Ltd Wallis Way Catcliffe Rotherham S60 5TZ

Related documents

- final1-figure-4a.pdf
- final1-figure-2a.pdf
- final1-oxigen-final-report-final.pdf

Last update: 20 June 2017
Record number: 199629

Permalink: https://cordis.europa.eu/project/id/310279/reporting

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