EQUINOX

A novel process for manufacturing complex shaped Fe-Al intermetallic parts resistant to extreme environments

Volume 3

Horizon 2020
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Project background

After World War II some east European countries were facing severe problems to buy Cr and shortage Ni on the free market to cover their needs for stainless steel production and materials for high temperature using.

To overcome this shortage countries of Eastern Block initiated a research in national research institutions, universities and local industry in the 50s – 60s to develop low cost alternatives for heat resistant cast iron and stainless steel alloys based on intermetallics casted from accessible and cheap Iron, Aluminium and Carbon.

These efforts result in the past in the materials such as Thermagal© Tchugal© and Pyroferal©. Pyroferal© offered quite impressive results on high temperature corrosion resistance. It was tested against various severe conditions, such as air atmosphere, vanadium pentoxide, molten glass, carburization, nitration and the atmosphere of the natural gas cracking generators.

Though Pyroferal© was manufactured only by casting, welding was the important procedure not only to produce complicated shapes, but also to repair the faults in casts. Unfortunately, the practical use of these materials was limited due to various problems.

These problems related to instability and welding could not be overcome by state of the art in material science at that time.
In the 60s, access to Chromium was no problem any longer and the dust of history covered the knowhow on (pre-) industrial use of FeAl. But things may change again. Chromium and Nickel are listed in the table of CRMs with a current projected lifetime of 25 - 100 years.

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Project overview

EQUINOX tries to blow away the dust of history from this early work on FeAl, aiming to combine latest state of the art in intermetallic metallurgy to overcome the problems that our ancestors were facing when they failed to translate unique corrosion and wear properties of FeAl into a low cost Cr/Ni-free alternative for stainless steel products.

There is a need to find solutions to replace Critical Raw Materials (CRMs) such as Chromium, Nickel, Molybdenium and Vanadium in high volume end consumer products. Steels and superalloys with considerable amounts of these CRMs are widely used in many industrial applications, particularly under extreme conditions where corrosion and wear resistance are needed.

It is generally accepted, that intermetallics in particular low cost FeAl offer outstanding material properties. Unfortunately it is difficult to translate their properties to real products, as intermetallics suffer from low ductility at ambient temperature and poor machinability.

The impact of FeAl intermetallics as a low cost Cr-free alternative for stainless steel would therefore be much higher if a cost effective industrial process would beavailable, that allows to manufacture complex 3-D geometries of almost unlimited shapes from small grain size (0.1-5 µm) high ductility material.

Objectives

The main objective of EQUINOX is to develop a novel process that allows to substitute Cr/Ni based (stainless) steel parts used in high volume end consumer products such as in the lock industry, electronics, process industry and automotive industry with a novel near net shape production technology for a new class of highlyadvanced ductile Fe-Al based intermetallics.

To produce extremely fine grained FeAl-Material with high ductility via reactive infiltration of porous iron preforms with liquid Aluminium.
To understand how ultrafine particle based porous iron structures of complex 3D-shape may be tailored to be used as optimized preforms for reactive infiltration of liquid Al-alloys.
To develop a reactive infiltration process by using two different techniques: suction and centrifugal casting.
To simulate reactive infiltration process by physically based multi-scale models based on StarCast and MICRESS.
To optimize mechanical properties of **EQUINOX** material with respect to microstructure based on process conditions and consecutive heat treatment.
To scale up the process from lab to small pilot plant with respect to the industrial needs.
To transfer the concept to at least one real demonstrator which will be tested for high corrosion and wear resistance.
To evaluate the industrial impact of **EQUINOX-concept** with respect to economic as well as technical aspects.l.

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Concept and approach

The **EQUINOX** process well fits into "Growing a Low Carbon, Resource Efficient Economy (1) with a Sustainable Supply of Raw Materials (2) - for materials under severe conditions (3)" by many aspects:

No CO2 is produced as side product as oxygen from raw material iron-oxide is fixed as H2O.
No waste of material: 100 % of the material that enters into the process chain ends up as final product of complex 3 D-shape.
No energy is used for "material tourism"
All steps of the process run at one single location – Fe3O4 and Al entering through the front door and final 3D-shaped Intermetallic parts leaving through the back door.
Solar heat may be used to cover most part of energy input as temperature level is just slightly above the melting point of Al in all steps involved.
The process may be completely based on H2(which could be made from renewable energy).
Materials with properties close to stainless steel are manufactured from abundant Fe and Al - without (or at least drastically reduced) CRM-materials Cr/Ni/Mo.
EQUINOX materials exhibit properties that withstand corrosion, cavitation and wear offering good results on LCA (life cycle analysis).

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Project Partnership

Eleven partners participate in the EQUINOX project, representing academic, applied research and industrial development.

NATIONAL TECHNICAL UNIVERSITY OF ATHENS

ELASTOTEC GmbH ELASTOMERTECHNIKEN

FUNDACION IMDEA MATERIALES

TECHNICKA UNIVERZITA V LIBERCI

ACCESS e.V.

OPEN SOURCE MANAGEMENT LIMITED

FRENI BREMBO Spa

YUZHNOYE DESIGN OFFICE NAMED AFTER MIKHAIL YANGEL,

INNOVATION IN RESEARCH AND ENGINEERING SOLUTIONS

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BREMBO

Brembo, along with partners KE and ACCESS, have analysed the EQUINOX process in order to find the best solutions to obtain a sound brake system prototype.
More than five different designs have been investigated, out of those four have been considered promising by the consortium. In addition, an advanced design which could help test the best EQUINOX material in a simplified way has been produced.
Currently moulds for the KE preform production are being manufactured. In particular, a mould for the "advanced design" is already available at KE facilities, while the mould for the main prototype is undergoing the production process.

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Fig.1: 5-axis CNC Milling machine Mikron UCP710 used for experiments

ELASTOTEC

ELAS has worked on D 5.6:

CNC milling is probably one of the most important operations in subsequent machining of Equinox material. Milling experiments help us to find proper cutting parameters and tool qualities. We performed milling experiments on a 5axis milling machine (Mikron 710 CP) starting with reference materials to evaluate best cutting conditions. We used a variety of mills and different cooling strategies. For each mill varied the milling parameters cutting speed, feed, side feed, tooth feed and inspected the tools after certain cutting times for erosion phenomena on the cutting edges.

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The quality of the milled surface and the tools were checked after each milling experiment and documented. After having identified proper mills and milling conditions we used these parameters for milling Equinox materials. We started with infiltrated samples not heat treated from Access and continued with heat treated Equinox material from TUL.

Fig.2: Mill traces after 5 experiments on Fe3Al reference material

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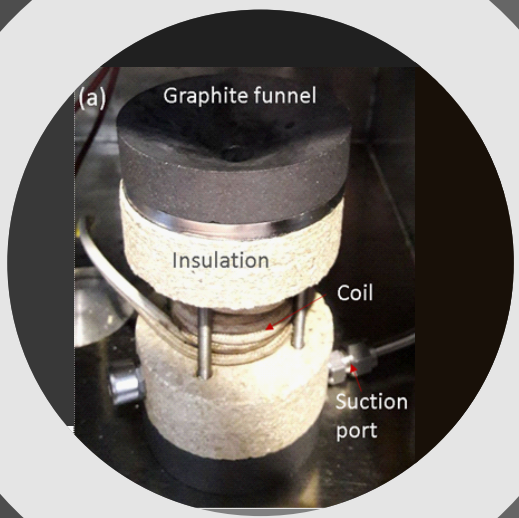

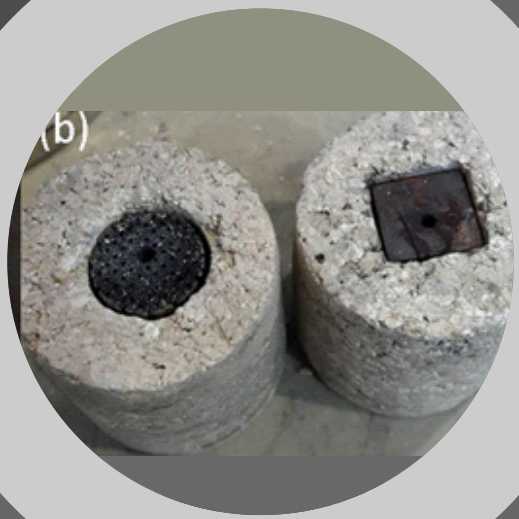

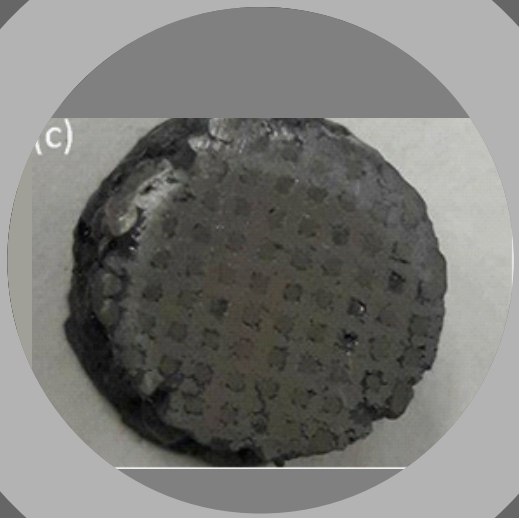

IMDEA MATERIALS

Reactive pressure-assisted infiltration of Iron-Aluminum melts into porous Iron preforms using the suction casting process has been studied by the IMDEA Materials partner (Spain). The IMDEA´s group dealt with a design of the infiltration device and further process parameters tuning (e.g. suction pressure).
The additional process parameters used in the experiments were selected on a basis of the calculations of the modelling group of Access e.V. As it can be seen from the images depicted below, a successful infiltration has been performed.
For the next step of EQUINOX´s project, a further post heat treatment is foreseen on the infiltrated samples. This will enable a further transformation of the obtained phases into desired ultrafine intermetallic phases.

Figures 3: (a) pressure-assisted infiltration device, (b) vermiculite crucible in a two different geometries, that is, cylindrical (left) and square(right) shapes. A snapshot of a section of infiltrated porous Selective Laser Melting –made Iron preform using Iron-Aluminum melts is depicted in picture (c).

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Work Group Meeting
16 June 2017, Prague, Czech Republic

EQUINOX consortium contributed with an oral presentation that presented the EQUINOX project

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Figures 4: CRM banner

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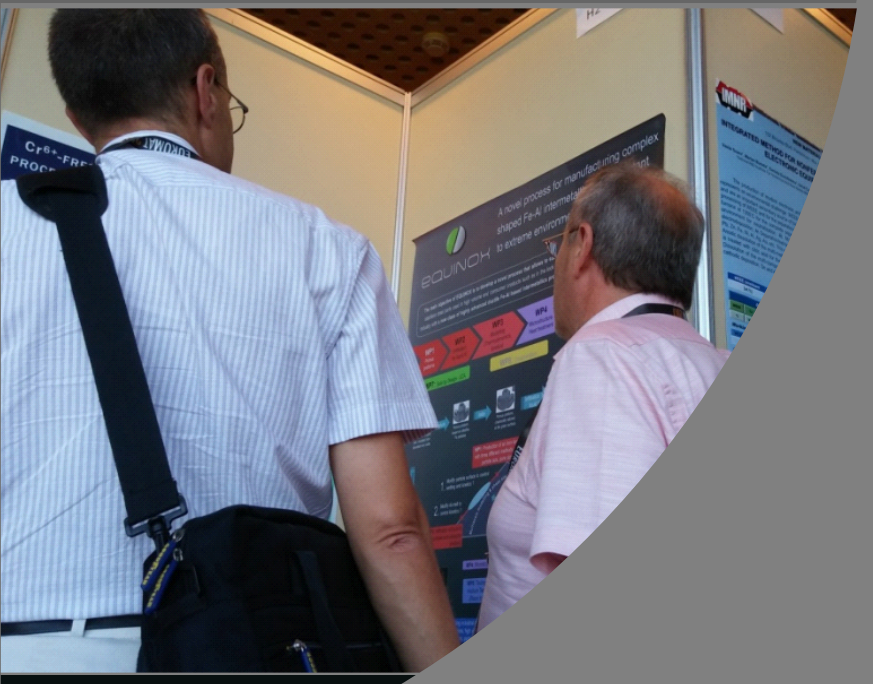

Figures 5: (a) EUROMAT 2017 Banner, (b) EQUINOX Poster presentation.

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Dissemination activities

EQUINOX consortium was represented by NTUA in the EUROMAT 2017

Towards highly advanced, non-brittle Fe-Al based intermetallics

W. Kochanek, S. Milenkovic, S. Jana, P. Hanus, P. Kavouras,

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Dissemination activities

An innovative route for advanced non-brittle Fe-Al based intermetallics
W. Kochanek and C.A. Charitidis

Symposium I: Solutions for critical raw materials under extreme conditions. 12-21 September 2017
Organized by CRM-Extreme COST Action

Figures 6: Symposium Banner.

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Figures 7: Raw Materials Week banner.

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Dissemination/Clustering action

1st Annual Critical Raw Material Event on November 7th 2017 in Brussels

Opportunity, to a variety of stakeholders, to get a fresh update about the latest EU activities in the field of Critical Raw Materials.
EQUINOX consortium contributed with an oral presentation that presented the EQUINOX project.

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Figures 8: C-MAC Days

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Dissemination/Clustering action

C-MAC Days 2017 was organized in Athens, Greece, from 20 to 23 November 2017.
The main purpose of C-MAC Days is to provide comprehensive information on recent results achieved within the current year of the C-MAC network and to discuss directions for future research.
EQUINOX consortium contributed with an oral presentation entitled: Innovative Fe-Al intermetallics through an innovative production route

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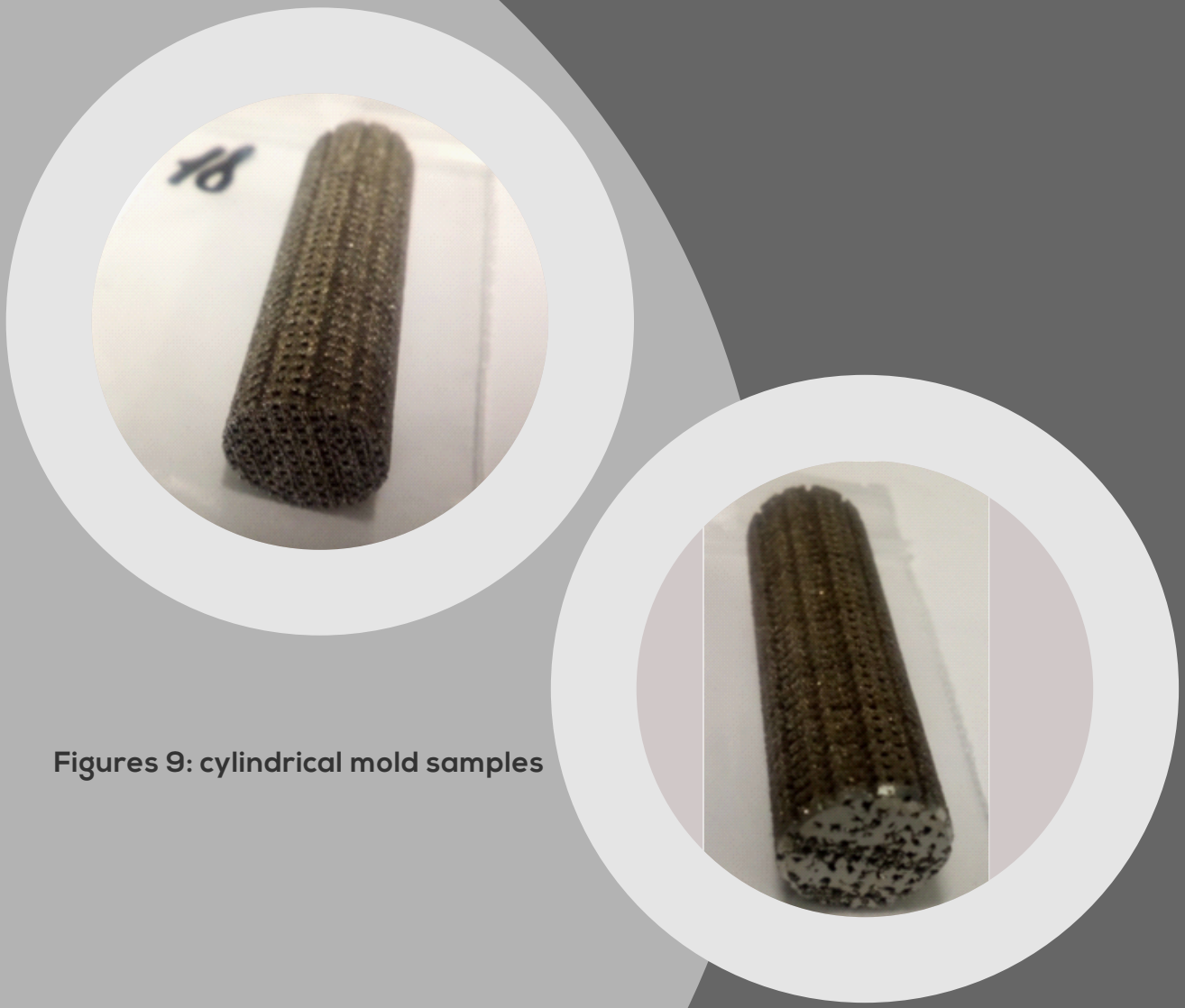
Main actions M16-M13

1)Manufacturing of extra batch of 20 SLM cylindrical mold samples;



Figures 9: cylindrical mold samples

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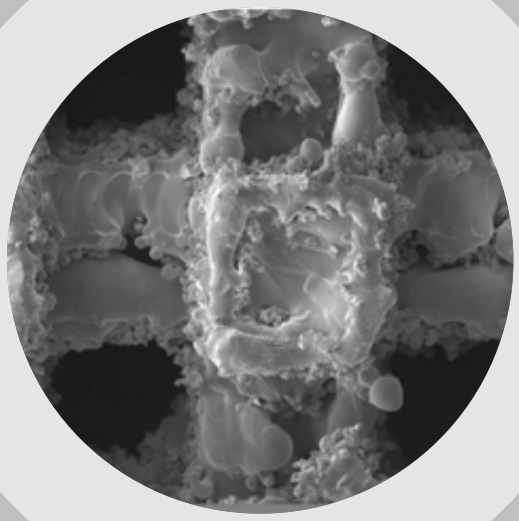
YUZHNOYE

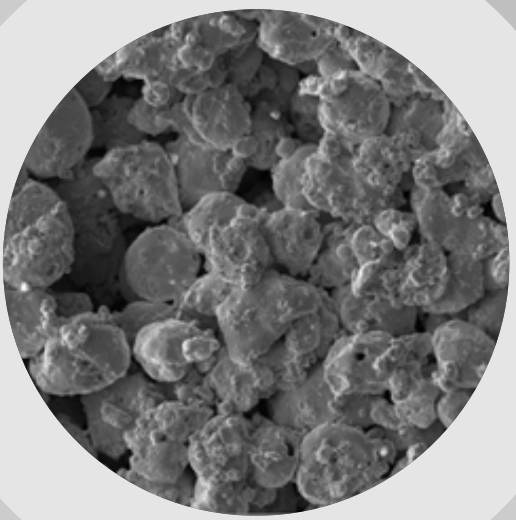
Main actions M16-M13

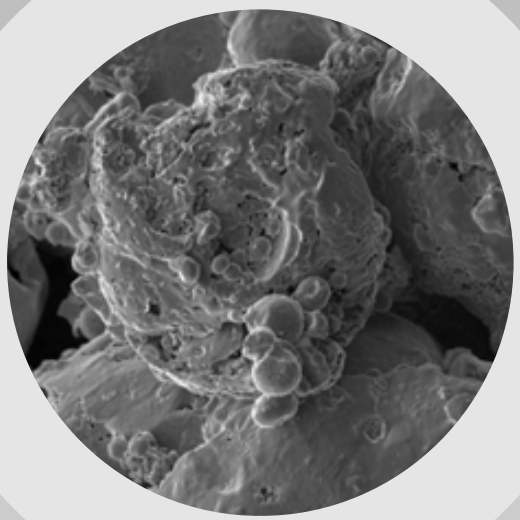
2) Studying of microstructure of manufactured samples obtained by different methods to define the optimum modes of liquid aluminum in filtration:

1. SLM preforms.
2. obtained by powder metallurgy method.
3. compressed iron turnings



Figures 11-12: SLM preforms:





Figures 13-14: obtained by powder metallurgy method

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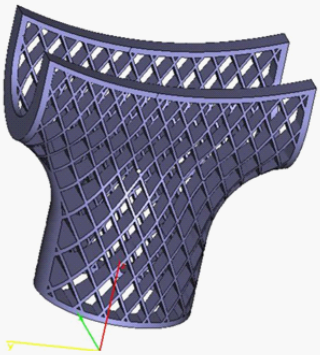
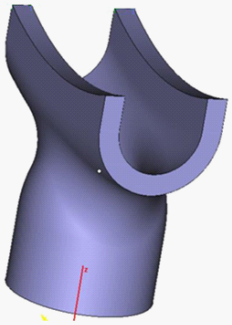
Main actions M16-M13

Figures 14-15: compressed iron turnings

3)Actions on development and optimizing of joint pipe 3D-model based on the results of WP1 (porousmatrixes), WP2, WP3 (infiltration) and WP4 (microstructure and-post heattreatment).





Figures 16-17: 3D Models.

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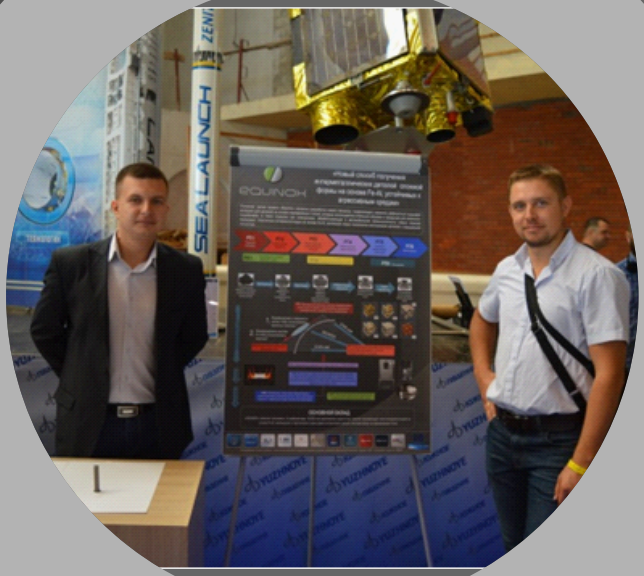

YUZHNOYE

4)Participation in Inter pipeTech Fest 2017 that was held on September 16-17, in Dnipro (Ukraine). In frame of this event Yuzhnoye SDO presented the main concept of Equinox project.

Figures 18-19: Tech Fest 2017

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More info on Equinox-project

www.equinox-project.eu

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