Deliverable REPORT

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Abstract (for dissemination)	Current and ongoing standardisation on testing and analysis and the applicability to ManSYS objectives. Standard for Exchange of Product Model Data for transfer standard. Rules to enable the creation of dynamic network of certified laboratories including basic set of classifying parameters.		
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[1] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

Contents

"Scope of this deliverable":

- For a proper functioning of the ManSYS platform some specific needs and requirements on Quality Management and Standardisation are defined in: D3.1; WP5.
  We investigated the current and ongoing standardization on testing and analysis and the applicability to ManSYS objectives.
- Current international standards for testing and analysis
- Applicability of existing standards to ManSYS
- Standard for Exchange of Product Model Data for transfer standard
- Rules to enable the creation of dynamic network of certified laboratories including basic set of classifying parameters

1 Summary

This deliverable comprises the Technical Specification or a Technical report on AM standardization. It forms a technical report as a background structure for a European Standard. The focus is on Methods – Processes – Materials and Data processing.

For this, the ManSYS partners investigated the current international standards for testing and analysis as well as the applicability of existing standards to MANSYS objectives. The original DOW refers to coordination with STEP (Standard for the Exchange of Product Model Data), which is used for data transfer standards. However, in the meantime a new and improved file format AMF (additive Manufacturing File format) is introduced which has additional features. In order to present the most up to date information in ManSYS, it was decided that AMF would be incorporated rather than STEP in our assessment and evaluations.

The definition of rules to enable the creation of a dynamic network of certified laboratories to perform objective testing of AM materials and designs was also incorporated. This includes the definition of a basic set of classifying parameters and the procedure to define new parameters.

D3.2 will be further elaborated and detailed to progress into D3.3. ManSYS D3.3 will deliver a structure of the quality system, where this deliverable D3.2 provides the basis for D3.3.

2 Introduction

This deliverable succeeds D3.1 and comprises the specifications and requirements for test methods, materials, processes and data processing as well as the definition of rules to enable the creation of a dynamic network of certified laboratories to perform objective testing of AM materials and designs.

By doing so it will form the basis for D3.3, being the AM control and automation as well as Process validation description and quality structure.

The later ManSYS D3.3 will deliver a structure of the quality system, where this deliverable D3.2 will provide the foundation. D3.2 will be further expanded and appraised into D3.3 which will be an outline structure of the quality system and standards for the certification of conformity.

The structure of D3.2 is:

- Standards for Test Methods
- Standards for Materials qualification
- Standard for Process monitoring systems
- Standards for Dataprocessing
- Criteria for test laboratories

An important source of information for this report is the SASAM project deliverable D3.3 “Guidelines for the development of the EU standards in Additive Manufacturing”, which was kindly provided by the SASAM project.

3 Standards for Test Methods

From the SASAM project (SASAM deliverable D3.3) we learned that the test methods under consideration for AM comprise test methods to characterise materials and machines dedicated to AM and final products regarding their physical, mechanical and other properties. We will extend the existing standards (rather than inventing new ones) in order to cover additively manufactured final products.

Two main groups already exist: mechanical test methods and geometrical conformity test methods:

1. **Standard characterization tests and methods used at present**
   Mechanical: tensile strength (ISO 6892-1:2009), residual elongation (ISO R204), modulus of elasticity (ISO 6892-1:2009), fatigue strength (ASTM E466:1996), etc.
   Geometrical conformity to the model (dimensions, details resolution, etc.)
2. **Physical / Mechanical / Other properties**
   Physical properties: exact composition, density, microstructure, CTE (ISO 22674:2006), etc.
   Mechanical properties (density, porosity, hardness, surface roughness, etc.)
   Sensorial aspects (visual, surface texture and roughness, etc.)

SASAM indicated that the criterion for selecting the most relevant standards is based on the information provided by suppliers of equipment and materials to their customers. Key standards have been selected according with the most common and usual standards shown in the material data sheets of manufacturers.

Table 1 shown below focuses on metals because of the available information. The second column of both tables explains those standards that are currently used by companies (based on conventional standards). The third column indicates recently approved standards by international committees (ISO, ASTM) and it is expected that these new standards replace the old ones in each particular test. The fourth column shows standards being in the process of being edited and approved.

It should be noted that not all existing standards related to one particular test resolves the full problem because some of them are partially applied. The SASAM D3.3 deliverable is provided as an Annex I for further detail.

Table 1 Actual standards for metals (Source SASAM D3.3)

TESTS	Nowadays Applied Standards	New existing AM standards	New ongoing AM standards	Identification of lacks relevant for AM
Mechanical Properties			ISO/CD 17296-3*	
Tensile Strength, Yield	ISO 6892-1:2009 ISO 22674:2006 DIN 50125	ASTM WK30107 New Practice for Reporting Results of Testing of Specimens Prepared by Additive Manufacturing	ISO YYY-1 .Additive manufacturing. Tensile test specimen	Operational parameters and build direction necessary in specimen geometry definition
Tensile Strength, Ultimate	ISO 6892-1:2009 ISO 22674:2006 DIN 50125	ASTM WK30107 New Practice for Reporting Results of Testing of Specimens Prepared by Additive Manufacturing	ISO YYY-1 .Additive manufacturing. Tensile test specimen	Operational parameters and build direction necessary in specimen geometry definition
Elongation at Break	ISO 6892-1:2009 ISO 22674:2006 DIN 50125	ASTM WK30107 New Practice for Reporting Results of Testing of Specimens Prepared by Additive Manufacturing	ISO YYY-1 .Additive manufacturing. Tensile test specimen	Operational parameters and build direction necessary in specimen geometry definition
Modulus of elasticity	ISO 6892-1:2009 ISO 22674:2006 DIN 50125	ASTM WK30107 New Practice for Reporting Results of Testing of Specimens Prepared by Additive Manufacturing	ISO YYY-1 .Additive manufacturing. Tensile test specimen	Operational parameters and build direction necessary in specimen geometry definition
Hardness	ISO 6508-1 ISO 6507-1			Existing standard could be applied
Fatigue strength	ASTM E466:1996			Operational parameters and build direction necessary in specimen geometry definition
Thermal Properties				
Coefficient of Thermal Expansion	ISO 22674:2006			Existing standard could be applied

ISO/CD 17296-3 is a general standard which covers the principal requirements applied to testing of parts manufactured by additive manufacturing processes. This standard gives the list of characteristics and corresponding recommended test standards. These standards do not suit perfectly additive manufacturing because they were written prior to the development of additive manufacturing technologies. The broad variety of standards for metals in mechanical properties is due to the different materials where they are applied. CoCr Alloy, Ti6Al4V Titanium Alloy,etc.

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SASAM deliverable report D3.3 provides several conclusions and recommendations for future standardization for tensile testing, flexural testing, fatigue resistance, geometric tolerance, geometric requirements (technical drawings in AM).

4 Standards for Materials Qualification

Technical specification for materials shall identify and recommend the required topics for material specifications. This comprises raw material, processed material and recycled material and the AM standards covering materials. The list will be limited to the two main groups of materials: metals and plastics. In particular, the following metals are currently being studied/considered: (Co-Cr, TI-6AL-4V, CpTi Grade 1,2,5, Inconel 625 and 718, tool steels, Al and light alloys, gold, bronze, copper, silver, etc.)

SASAM D3.3 indicated that for all material mentioned, the following skeleton of normalisation should be built. In **bold** are indicated those relevant for materials:

a) **scope**: the scope should identify what type of material is covered by the standard, to whom it applies and for which technologies it is applicable.
Point of discussion: a comparative study on SLM and EBM processes when using Ti64 SLM & EBM as the build material has resulted in the following conclusions: Different surface structure – different microstructure – different tensile strength results – different ductility results – different fatigue limits. A comparative study using CpTi grade 1 & 2 as the build material is not available but should be considered. One could assume that the same differences are expected but that needs to be proven.
b) Reference documents
c) Terminology
d) Classification
e) Manufacturing plan
f) Safety
g) **Feedstock and recycling influence (particle size and shape)**
h) Process (separate category in ManSYS)
i) Chemical composition (oxygen pickup)
j) Microstructure
k) Mechanical properties (separate category in ManSYS)
l) Thermal process (stress relaxation)
m) **HIP**
n) Dimensions and permissible variations
o) Cleanliness of products
p) Retests
q) Certification
r) Quality program
s) Supplementary requirements

All categories are extensively described in the SASAM D3.3; also from D5.1 some specific information on metals EBM and SLM is provided:

As it is mentioned in the Standards ASTM-F2924 (Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion) and ASTM-F3001 (Additive Manufacturing Titanium-6 Aluminum-4 Vanadium EKI (Extra Low Interstitial) with Powder Bed Fusion):
The metal powder for EBM and SLM shall be metal powder that has the powder type, size distribution, shape, tap density, and flow rate optimised for the process as determined by the component supplier.

- The metal powder shall be free from detrimental amounts of inclusions and impurities and its chemical composition shall be adequate to yield, after post-processing, the final material chemistry listed in table 2 or table 3.
- Powder blends are allowed unless otherwise specified between the component supplier and component purchaser, as long as all powder used create the powder blend meet the requirements in table 1 or table 2 and lot numbers are documented and maintained.

Table 2 Chemical composition of Ti6Al4V

Element	min	max
Aluminum	5.50	6.75
Vanadium	3.50	4.50
Iron	—	0.30
Oxygen	—	0.20
Carbon	—	0.08
Nitrogen	—	0.05
Hydrogen	—	0.015
Yttrium	—	0.005
Other elements, each	—	0.10
Other elements, total	—	0.40
Titanium	remainder	

Table 3 Chemical composition of Ti6Al4V-ELI

Element	min	max
Aluminum	5.50	6.50
Vanadium	3.50	4.50
Iron	...	0.25
Oxygen	...	0.13
Carbon	...	0.08
Nitrogen	...	0.05
Hydrogen	...	0.012
Yttrium	...	0.005
Other elements, each	...	0.10
Other elements, total	...	0.40
Titanium	remainder	

As mentioned in ASTM F2924 and ASTM F3001 the blended powder is allowed but it is necessary to define a blended procedure that it is not specified in the standard. Moreover, it is crucial to assess that the final part material agrees with the powder requirements (Table 2 and Table 3) so a procedure to test the material in each build must be defined.

5 Standard for Process Monitoring Systems in Metal PBF AM Machines

In the AM process of Laser Melting of metals every individual spot of the work piece is produced by converting the feedstock material (metal powder) in to work piece materials by melting it with a laser. This process can be very sensible for distortions due to deviations of process parameters. To improve the reliability of the quality of the work piece it must be ensured that the complete process takes place within a predefined window of process parameters. Monitoring the process parameters - both the 'input' parameters such as laser power or scan velocity as well as the 'output' parameters such as melt pool temperature or size during the complete production will help to proof that the process took place within in predefined process conditions. Specific critical applications (e.g. medical and aeronautical) require strict quality assurance management with extensive traceability of the production process.

This chapter aims to assist the standardisation bodies to develop a standard on monitoring systems for metal PBF systems. It should help to make monitoring data available and be stored in a structured way so that monitoring data can be used for later analyses, quality management and traceability. This will help improve the reliability of AM manufactured parts making application in critical areas possible.

The standard to be developed will help machine tool users and machine tool developers to:

- define the sets of parameters to be monitored,
- guarantee the accuracy of the set of parameters that are monitored,
- store the monitored values in a structured way to meet requirements for traceability and analysis.

5.1 Definitions and back ground information

Control system in the AM machine

As illustrated in Figure 1 below the parameters for the scan strategies and process parameters are all defined during the preparation of the job for the AM machines. The geometry of the parts and support structures are sliced and the slices are filled with the details of the scan vectors and process conditions resulting in the complete "Build Profile" with detailed instructions for the PBF-process.

The Build Profile is fed in to the machine control software that successively executes the commands out of the build profile by sending the commands to the machine tool actuators. Different control systems (PLCs, …) transfer the comments in to successive e.g. movements of the building platform, recoater, galvanometer and material feeders and also the process setting for e.g. the temperature of the building plate and regulating the gas flows. Direct feedback in the control systems from sensors and servo systems is used for controlling the sub-systems.

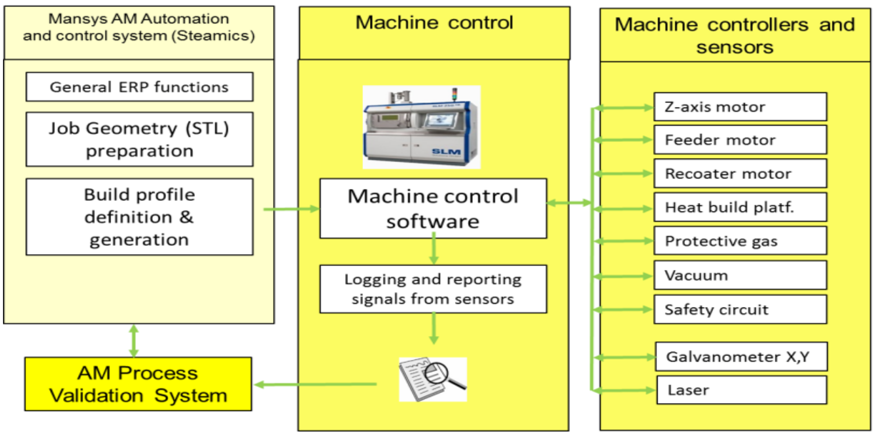

Figure 1 Parameters for the scan strategies and process parameters

Definition: Sensing and control
Sensing and control is applied when signals from sensors are directly used for control without feedback to the user or storage of the data. Only basic safety systems are put in action if extreme errors occur. Example: Basic servo control of linear axis. If there are large deviations a fuse might fail. Sensing and control cannot be addressed as monitoring within the scope of this report.

Definition: Monitoring with limited reporting and storage of data
'Continuously' sensing with directly using the signals for control and monitoring if the signal is out or in a predefined tolerance window. For example the following scenarios can occur:

a. The parameter signal is within a predefined tolerance window of the set value. The process is assumed to be under control and proceeds as planned (e.g. green light).
b. The parameter signal is out of tolerance with no risks. The process is not yet really in danger and could proceed but action is required. A warning might occur giving the operator the opportunity to take appropriate measures (Example: yellow light with warning low oil level). The produced part does not need extra attention. It might be applicable to store the warning traceable to the time when the warning occurred.
c. The parameter is out of tolerance and there is a severe risk to damage the machine or affect the quality of the built parts. The machine might need to be stopped and/or brought in to a safe mode.

The report and storage of monitored parameters in this category might be minimised to a conformation that during the build the parameter is always within the predefined tolerance window. In case of deviations outside the predefined window it should be clearly reported that the value was out of tolerance traceable to the time and to individual produced parts. Further details on the sensed parameter might be useful to be monitored (and stored) like the largest deviations that occurred traceable to the individual part and height of the individual parts. Extensive monitoring of sensed parameters in a certain sample frequency could be useful.

Definition: Monitoring with external data acquisition and data storage
Monitoring with external data acquisition and storage of the data is usually applied when the monitored parameters are needed for traceability and/or later analyses. For example taking high resolution photos of the powder bed or logging certain process signals. It might be required that these images are stored traceable to the individual job and build height.

5.2 Requirements for monitoring systems

The reliability of sensors used for monitoring must be guaranteed by calibration and maintenance programs according to appropriate quality management measures.

The monitored signals should be stored in a structured way and be available via standardized interfaces.

Filters applied to the raw signals should be defined: type of filter (e.g. Butterworth), filter parameters (e.g. in a low pass filter the cut-off frequency). The sample frequency and accuracy should be appropriate for the purpose for which the monitored signals are needed. An order of magnitude for the sampling frequency would be 500 - 1000 Hz.

The monitored data must be traceable to the specific sensors and if applicable to the individual part that was build and the to the build height of this part.

If actions are undertaken based upon the values of monitored parameters the tolerance windows should be clearly defined, documented, reported and accessible using secure data storage with measurements against data loss, manipulation regarding confidentiality issues.

Parameters to be monitored
All process parameters that could affect the quality of the produced end part are potential subject for monitoring. Obvious items include:

- Temperature of the building plate,
- Laser/EB power,
- Oxygen content in the build chamber,
- Differential pressure over filter units, melt pool size, encoder signals from servos.

The application might set requirements for the parameters to be monitored and storage of monitored signals.

The possibilities for advanced monitoring of for example melt pool size and temperature will expand as metal PBF is subject of research and development.

Deliverable D5.2 explains the different reporting schemes for the internal control systems for EBM and SLM. It comprises of a status report, event report, build report, system status report, system progress report and System Build Log.

The SLM systems keep a number of logs of the various sensors that can be reviewed after a build to ensure that the build will be completed as required. An example of the log files can be seen in Appendix I-6. The log includes laser power used, laser current, time per layer, argon gas flow, oxygen content, and gas pressure. The log represents a complete review of the build from start to finish, which is a mandatory action for performing the processes in a standardised manner. For the details of the different process status reports, deliverable D5.2 is referred to.

6 Standards for Data Processing STL/AMF

6.1 Introduction

The most common used file format that represents the geometry of the part to be produced with additive manufacturing is currently STL (Standard Triangular Language).

Recently the Additive Manufacturing File format is introduced (AMF). The first version is depicted in Annex III (front page and table of contents). Basically the STL-file is incorporated in to the AMF format and some extended possibilities for e.g. multi material, graded structures and repetitive unit cells are incorporated in the AMF file format. However at the moment AMF is not widely used. ManSYS will monitor its development and implementation. For the ManSYS platform we will apply the STL format.

A reliable STL/AMF file is the basic geometrical information for the AM-production process. Each CAD package has different output methods. Currently there are quite often problems with STL files.

6.2 Common problems with STL-files

Common problems with STL files are the accuracy of the file and inconsistencies (for example bad edges, holes, inverted normals). These are usually issues that are inevitably caused by conversion from CAD to STL. There is software available for quality checking, which is recommended to be used. ManSYS will help users to identify these issues before submitting a part to the ManSYS platform. In the current situation these problems later must be repaired and in most of the cases this is done by the AM service provider. That makes the service provider responsible for certain changes in the original geometry. Repairs done by the service provider are mostly not incorporated in the original design. So if the original design is changed the new version again needs to be ‘repaired’.

Cad systems have their own STL-generators and the quality of generated STL files can vary a lot. CAD systems can be divided in two main groups being the Solid Modelers and the Surface Modelers. Solid modelers provide normally ‘solid’ and water tight models. This is the desired precondition for generating good quality STL-files. Surface modelers allow combining different independent surfaces together and thus forming a solid model. Problems arise if the surfaces do not exactly match at the edges leaving open space of cross each other. Surface modelers might have tools for stitching surfaces together and unify operations that cut the edges of crossing surfaces. Designers using surface modelers that are not familiar with the requirements for STL when used for additive manufacturing might produce not really solid parts. These problems should be solved in the root thus in the design phase and not be ‘repaired’ afterwards by the AM service bureau.

In the ManSYS project the first case study is performed on two STL-files provided by Wisildent. Repairing one of the STL-files was not easy and caused an inconsistency in the design. Detailed screen shots are available in a word document which can be downloaded from the ManSYS FPT-site (WP3.1). The other two case studies from the industry participants are currently underway.

6.3 ManSYS needs and requirements

ManSYS needs and requirements for quality management and standardisation regarding to STL/AMF-files are:

- The way how CAD-systems produce STL files must be standardised and validated so reliable and uniform STL-files will be produced with well-defined accuracy of the STL-file.
- The STL may not have “inverted normals”, “bad contours”, “no bad edges”, “near bad edges”, “planar holes”, “noise shells” or “inverted normals”. Repairing the STL file should not be needed. In fact repairing the STL-file is changing the geometry of the “ordered geometry” and makes the service provider responsible for the design. So repair of the STL-file is not allowed.
- There needs to be a standardised test procedure to validate the STL-file generator of the CAD-system.
- The STL-file generated by the CAD-system must represent the geometry of the design as specified in the CAD-file with an accuracy < 0,01 mm.
- Multiple shells in a part cannot always be classified as an error. In case of hollow parts the part will contain multiple shells (no error). In other situations (complex parts) the multiple shells can have a function as one shell represents a section of the part where a lightweight structure needs to be applied. In other cases it could be an error. It is recommended that multiple shells are automatically detected so that the user can respond accordingly to it.
- The STL-file must be checked with the STL-software module in ManSYS (similar function as Magics) and must result in a report confirming that there are no errors in the file as previously defined. Repairs of the STL-file are NOT allowed. If STL errors occur the repairs must be done in the source (CAD-system / CAD-file) and not in the STL file.
- The processed and checked STL file will be used to define the support structures. The complete geometry of the part and the support structures must be stored according requirements for tractability and confidentiality.
- A relative new file format is the AMF-format in which STL-data is incorporated. The AFM format is defined in ISO/ASTM 52915 “Standard Specification for Additive Manufacturing File Format” (AMF) version 1.1.ManSys must be able to use AMF-format in the same way as STL.
- Specific requirements from Wisildent and Twocare:
- Wisildent and Twocare application are designed using dental scanner and dedicated dental software that “close” the CAD file creating a STL file and it is impossible to modify this file internally. In the case of errors in the file it is necessary to give a warning.
- The STL file from Wisildent and Twocare is like a closed surface but empty inside. It will be necessary to “fill” the file with “virtual material” in a lattice structure to be sliced by the “slicing SW” and if necessary also to add “holes” inside to reduce the weight of the prosthesis. Please

note that these actions will be performed outside of the ManSYS platform and that they require additional software such as Magics and exported as a *.magics file.

6.4 Basics of STL-file

The geometry is composed out of triangles.

- Every triangle has got three end points
- Every end point has got three coordinates (x, y, z)
- Every triangle has got a normal vector indicating the direction of the material

Example Box 20 x 40 x 60

A box can be defined by 12 triangles as shown in Figure 2.

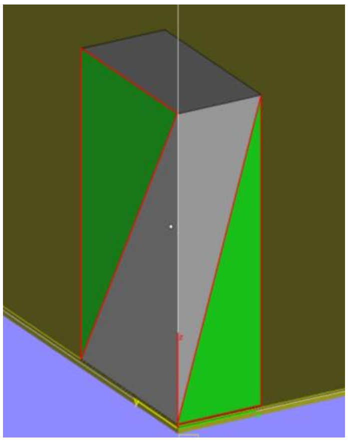

Figure 2 Example box

Below the STL-file of this box is given

```
solid
facet normal 1.000000 0.000000 -0.000000
outer loop
vertex 20.20000000 40.40000000 0.60000000
vertex 20.20000000 40.40000000 60.60000000
vertex 20.20000000 0.40000000 0.60000000
endloop
endfacet
facet normal 1.000000 -0.000000 0.000000
outer loop
vertex 20.20000000 0.40000000 60.60000000
vertex 20.20000000 0.40000000 0.60000000
vertex 20.20000000 40.40000000 60.60000000
endloop
endfacet
facet normal -0.000000 -1.000000 0.000000
outer loop
vertex 20.20000000 0.40000000 0.60000000
vertex 20.20000000 0.40000000 60.60000000
vertex 0.20000000 0.40000000 0.60000000
endloop
endfacet
facet normal 0.000000 -1.000000 0.000000
outer loop
vertex 0.20000000 0.40000000 60.60000000
vertex 0.20000000 0.40000000 0.60000000
vertex 20.20000000 0.40000000 60.60000000
endloop
```

```
endfacet
facet normal -1.000000 0.000000 0.000000
outer loop
vertex 0.20000000 0.40000000 0.60000000
vertex 0.20000000 0.40000000 60.60000000
vertex 0.20000000 40.40000000 0.60000000
endloop
endfacet
facet normal -1.000000 -0.000000 -0.000000
outer loop
vertex 0.20000000 40.40000000 60.60000000
vertex 0.20000000 40.40000000 0.60000000
vertex 0.20000000 0.40000000 60.60000000
endloop
endfacet
facet normal -0.000000 1.000000 0.000000
outer loop
vertex 0.20000000 40.40000000 0.60000000
vertex 0.20000000 40.40000000 60.60000000
vertex 20.20000000 40.40000000 0.60000000
endloop
endfacet
facet normal 0.000000 1.000000 0.000000
outer loop
vertex 20.20000000 40.40000000 60.60000000
vertex 20.20000000 40.40000000 0.60000000
vertex 0.20000000 40.40000000 60.60000000
endloop
endfacet
facet normal -0.000000 -0.000000 -1.000000
outer loop
vertex 20.20000000 40.40000000 0.60000000
vertex 20.20000000 0.40000000 0.60000000
vertex 0.20000000 0.40000000 0.60000000
endloop
endfacet
facet normal 0.000000 0.000000 -1.000000
outer loop
vertex 0.20000000 0.40000000 0.60000000
vertex 0.20000000 40.40000000 0.60000000
vertex 20.20000000 40.40000000 0.60000000
endloop
endfacet
facet normal -0.000000 0.000000 1.000000
outer loop
vertex 20.20000000 40.40000000 60.60000000
vertex 0.20000000 0.40000000 60.60000000
vertex 20.20000000 0.40000000 60.60000000
endloop
endfacet
facet normal 0.000000 -0.000000 1.000000
outer loop
vertex 0.20000000 0.40000000 60.60000000
vertex 20.20000000 40.40000000 60.60000000
vertex 0.20000000 40.40000000 60.60000000
endloop
endfacet
endsolid
```

6.5 General requirements for STL/AMF-files and examples

Accuracy

A ‘rough’ and inaccurate STL-file mostly shows flat artifacts on curved surfaces. An example is given in Figure 3.

The required accuracy of the STL file is based upon:

- The difference between the geometry of the original design (e.g. defined in the CAD-file) and the geometry of the STL file.
- The resolution and accuracy of the applied AM process.

Usually it is not practical to produce an STL-file that is over 3 times more accurate than the resolution of the applied AM process. So if and AM-process has a layer thickness of 0.15 mm the accuracy of an STL file should be at least 1/3 of 0,15 = 0,03 mm.

Most applied metal PBF processes have a layer thickness > 0,02 mm. The accuracy of the STL-file should be good enough to deliver an acceptable level of part faceting, in most cases implying accuracy up to 0.01 mm.

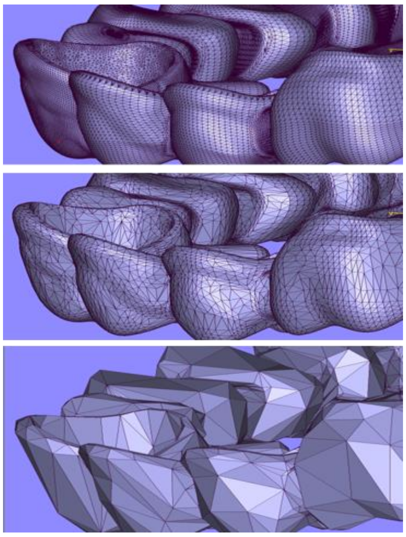

Figure 3 Three levels of accuracy of the STL file

Normal Vectors

The normal vector of a triangle (indicated in Figure 4) defines the direction in which the product material is present. So the normal vector of each triangle should be pointed towards the material. In most STL-viewers the side of the triangle towards the material is colored red. Figure 4 shows red triangles to what seems the outside of the part. These so called ‘flipped’ triangles are not acceptable. A STL-analyser should run a mathematical algorithm to check this. Each flipped triangle should be counted and reported.

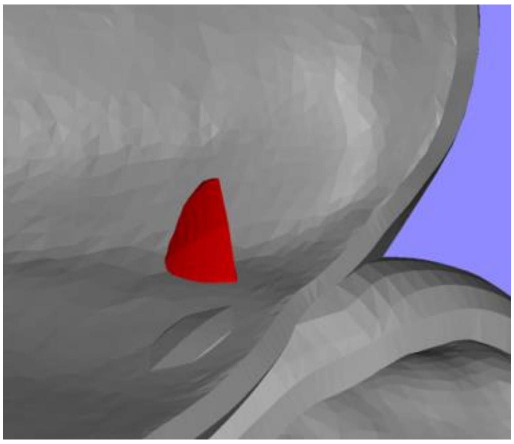
Figure 4 Detail of a normal vector of an STL file

Manifold / open edges
All triangles describing the geometry of the part together should form a water tight (manifold) surface. Figure 5 shows a non-manifold cube. The front surface does not fit to other sides of the cube leaving two open slots.

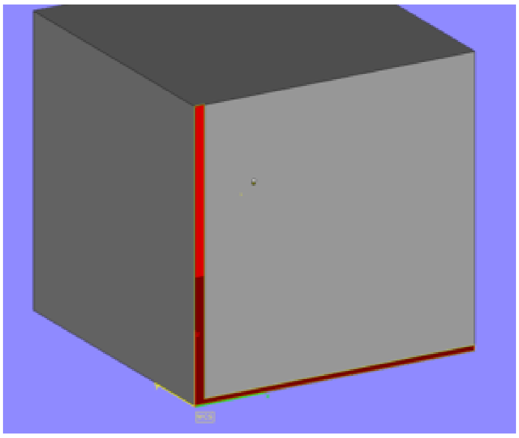
Figure 5 Detail of a non-manifold STL

Bad edges / Bad contours
Every side of each triangle should be covered by exactly one side of another triangle. Unmatched edges can lead to holes in the model.

Noise shells
Another phenomenon/issue is the noise shell, defined as a negligible total surface / volume with regards to the geometry of the whole part. It can be resolved by having the 1 shell requirement, which should be mandatory for the ManSYS platform data input.

6.6 Link with STEP

As indicated, there will be coordination with STEP by having our results and recommendations of this report checked by members of the existing STEP TC (Technical Committee). ManSYS will contact one of the members to arrange this (person involved is Klas Boivie from SINTEF, also SASAM partner).

7 Criteria for Test Laboratories

In order to implement the proposed topics and details for AM quality standards, there is also a requirement for the qualification of the laboratories doing the testing. For this ManSYS performed an investigation and proposes to follow the recommendations and requirements as mentioned under ISO/IEC 17025 'General requirements for the competence of testing and calibration laboratories". The content of this norm comprises and describes requirements for a.o. (full document in Annex II):

1 Scope
2 Normative references
3 Terms and definitions
4 Management requirements
- 4.1 Organisation
- 4.2 Management system
- 4.3 Document control
- 4.4 Review of requests, tenders and contracts
- 4.5 Subcontracting of tests and calibrations
- 4.6 Purchasing services and supplies
- 4.7 Service to the customer
- 4.8 Complaints.
- 4.9 Control of nonconforming testing and/or calibration work
- 4.10 Improvement
- 4.11 Corrective action
- 4.12 Preventive action
- 4.13 Control of records
- 4.14 Internal audits
- 4.15 Management reviews

5 Technical requirements
- 5.1 General
- 5.2 Personnel
- 5.3 Accommodation and environmental conditions
- 5.4 Test and calibration methods and method validation
- 5.5 Equipment
- 5.6 Measurement traceability
- 5.7 Sampling
- 5.8 handling of test and calibration items
- 5.9 Assuring the quality of test and calibration results
- 5.10 Reporting the results

ManSYS proposes to have all calibration laboratories and departments comply with above criteria.

Annex I Normalisation guidelines for metals/ Titanium Grade1 (Source SASAM project D3.3)

Key contributors for this information were the SASAM partners Layerwise, Sirris and Enise

Normalisation guidelines for Titanium Grade1
Input of LayerWise

SCOPE OF THIS REPORT
The scope of this report is to study the existing status of unalloyed titanium in the field of additive manufacturing and focused on medical applications, making some recommendations for future standards.

EXISTING STANDARDS FOR UNALLOYED TITANIUM
There are 4 different grades (Grade 1,2,3,4) defined for commercially pure Titanium often referred to as Cp-Ti or TiCp. For the application in the medical field mainly grade 1 and 2 are used for AM with Powder bed fusion.

Both ISO as well as ASTM have a standard covering unalloyed titanium which is specified to the fields of surgical implant applications but both are established for unalloyed titanium processed by traditional processes namely wrought and cast unalloyed titanium.
ISO 5832-2:1999 Implants for surgery -- Metallic materials -- Part 2: Unalloyed titanium.
This standard is part of a set of 12 standards covering metallic materials for implants for surgery.
It covers normative reference of chemical composition, microstructure, mechanical properties and testing.
The ISO 5832-2:1999 provides information for unalloyed titanium grades:
Grade 1 - to grade 4A and 4B.
Testing refers to other standards like: ISO 6892 for mechanical properties testing and ASTM E 112 for grain size determination.
There is no reference to or additional information on Additive manufacturing.

ASTM F67 Standard Specification for **Unalloyed Titanium, for Surgical Implant** Applications. Developed by Subcommittee: F04.12.
Same comments as with ISO applies here. There is no reference to or additional information on Additive manufacturing.

ONGOING STANDARDS ABOUT POWDER BED FUSION FOR UNALLOYED TITANIUM
ASTM F42 committee is currently not foreseeing to work on a standard for additive manufacturing of unalloyed titanium with powder bed fusion for medical application.
ISO is currently not foreseeing to work on a standard for additive manufacturing of unalloyed titanium with powder bed fusion.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STANDARDISATION
The following figure shows the structure as adopted by SASAM in the road map. It is necessary to decide the way of fitting unalloyed titanium in particular the different unalloyed titanium grades to this structure. The issue is whether there should be a different standard for unalloyed titanium grade 1 and grade 2 or whether they may be incorporated into one standard. In comparison to ASTM there is a different standard for Ti6Al4V grade 5 and Ti6Al4V grade 23 (ELI).
It is our recommendation to create only one standard for the different unalloyed titanium grades.
Following the line of separation should there be a different standard for EBM and SLM. This should be discussed by experts in more detail.

CONTENT OF FUTURE STANDARD FOR Powder bed fusion for unalloyed titanium:
A. Scope
The scope should identify what type of material is covered by the standard, to whom it applies and for which technologies it is applicable. The following is a possible description of the scope of the

standard. The larger part is comparable to the existing standards for AM powder bed fusion ASTM F3001

1.1 This specification covers additively manufactured titanium Commercially Pure TiCp Grade 1 and 2 components using full-melt powder bed fusion such as laser melting and electron beam melting. The components produced by these processes are used typically in applications that require mechanical properties similar to machined forgings and wrought products. Components manufactured to this specification are often, but not necessarily, post processed via machining, grinding, electrical discharge machining (EDM), polishing, and so forth to achieve desired surface finish and critical dimensions.

Point of discussion: a comparative study on SLM and EBM processes when using Ti64 SLM & EBM as the build material has resulted in the following conclusions:
Different surface structure – different microstructure – different tensile strength results – different ductility results – different fatigue limits.
A comparative study using TiCp grade 1 & 2 as the build material is not available but should be considered. One could assume that the same differences are expected but that needs to be proven.

H.K. Rafi, N.V. Karthik, Haijun Gong, Thomas L. Starr, and Brent E. Stucker. Microstructures and Mechanical Properties of Ti6Al4V Parts Fabricated by Selective Laser Melting and Electron Beam Melting (Submitted March 1, 2013; in revised form May 23, 2013)

All information within the standard should, if it covers both technologies and to avoid confusion, specify the difference between both technologies and if doing so would it not be better to split up the standard and have one for each technology.

ASTM F42 already started creating workgroups focusing on one technology:
WK28741 New Specification for Electron Beam Melting (EBM) Titanium 6Al-4 V ELI. and WK25296 New Specification for Electron Beam Melting (EBM) Titanium 6Al-4V.
While they already published a standard for powder bed fusion technologies (SLM & EBM) for both materials.

1.2 This specification is intended for the use of purchasers or producers or both of additively manufactured TiCp grade 1& 2 components for defining the requirements and ensuring component properties.

1.3 Users are advised to use this specification as a basis for obtaining components that will meet the minimum acceptance requirements.

1.4 User requirements considered more stringent may be met by the addition of those requirements to the purchase order and agreed upon by purchaser and supplier. These supplemental requirements can consist of, but are not limited to, the tests described under section S.

B. Referenced documents

Following ISO standard can be used as reference documents in this standard.
ISO 28401:2010 Light metals and their alloys -- Titanium and titanium alloys -- Classification and terminology
ISO 4490:2008 Metallic powders -- Determination of flow rate by means of a calibrated funnel (Hall flowmeter)
ISO 3252:1999 Powder metallurgy -- Vocabulary
ISO 3923-1:2008 Metallic powders -- Determination of apparent density -- Part 1: Funnel method
ISO 4491-1:1989 Metallic powders -- Determination of oxygen content by reduction methods -- Part 1: General guidelines
ISO 4491-4:2013 Metallic powders -- Determination of oxygen content by reduction methods -- Part 4: Total oxygen by reduction-extraction
ISO 22961:2008 Titanium and titanium alloys -- Determination of iron -- Atomic absorption spectrometry
ISO 6892-1 Metallic materials - Tensile testing - Part 1 Method of test at room temperature
ISO 6506-1:2005 Metallic materials -- Brinell hardness test -- Part 1: Test method
ISO 3738-1:1982 Hard metals -- Rockwell hardness test (scale A) -- Part 1: Test method
ISO 1099:2006 Metallic materials -- Fatigue testing -- Axial force-controlled method

ISO 12111:2011 Metallic materials -- Fatigue testing -- Strain-controlled thermomechanical fatigue testing method
ISO 4883:1978 Hard metals -- Determination of contents of metallic elements by X-ray fluorescence -- Solution method
ISO 22963:2008 Titanium and titanium alloys -- Determination of oxygen -- Infrared method after fusion under inert gas
ISO 28279:2010 Sintered metal materials -- Determination of the level of cleanliness of powder-metallurgy parts
ISO/ASTM 52921:2013 Standard terminology for additive manufacturing -- Coordinate systems and test methodologies

C. Terminology

Terminology relating to Coordinate systems en test technologies ISO/ASTM 52921:2013 shall be applied.

D. Classification

A certain classification should be created as different products will have different functions. This can go from providing artistic products that only have an aesthetic function to products that must withstand the most stringent requirements.
recommendation for classification:

Classification A: as build
Classification B: Stress relief
Classification C: Solution annealing. Reason for solution annealing would be for homogenization of small impurities.Classification D: HIP (Hot Isostatic Pressing)

E. Manufacturing plan

A manufacturing plan should be set up containing at least the processing steps taken. Purchaser and supplier shall agree on the manufacturing route.

A manufacturing plan typically provides information on:

1.1. The material to be used (feedstock)
1.2. The machine to be used.
1.3. The job file containing all product relevant information
1.4. The Process steps taken after AM production of the part (can be one step or many steps)
1.5. Specific requirements agreed upon between purchaser and supplier

F. Safety

The standard should contain or at least refer to safety related matters as metal powders are very small and some can cause damage to personnel's health when exposed intensively for longer periods of time.
The supplier shall have access to the MSDS sheets of the powders used and shall adhere to the guidelines provided by the powder suppliers. If such guidelines are missing, the supplier shall himself provide guidelines to his personnel directly working with powder. These guidelines should at least contain information about: storage, housekeeping, emergency precautions, handling and use.

G. Feedstock and recycling influence

In medical applications contamination risk should be avoided at all times. Many times different powders are used in the same machine. A requirement stating that pure titanium medical parts should only be produced on dedicated machines would seriously minimize that risk for contamination.

The powder should fulfill the chemical composition of the material and the tolerance of the analysis used should be within the given criteria.

"For clarification reason": ISO does not mention analysis tolerance, ASTM does.

Some kind of recyclability/mixing instructions should be provided. At least the chemical composition of each individual material in one batch should fulfill all chemical composition criteria before batches can be mixed.

H. Process

A material/machine release process is a minimum requirement to provide sufficient assurance to the purchaser that the products will fulfill the agreed requirements. This release shall be validated by substantial testing of machine/material combination. Running a product on any machine without validation can lead to adverse effects and needs to be avoided.

I. Chemical composition

This information comes from ASTM F67.
ISO does not mention analysis tolerance.

Element	Grade 1 UNS 50250 (Maximum)
Nitrogen, Max	0.03
Carbon, max	0.08
Hydrogen, max	0.015
Iron, max	0.2
Oxygen, max	0.18
Titanium	balance

Element	Limit or Maximum of Specified Range %, (mass/mass)	Tolerance Under the Minimum or Over the Maximum Limit
Nitrogen	Up to 0.05	0.02
Carbon	0.1	0.02
Hydrogen	Up to 0.015	0.0020
Iron	Up to 0.25	0.1
Iron	Over 0.25	0.15
Oxygen	Up to 0.2	0.02
Oxygen	Over 0.2	0.03
Titanium	balance	balance

J. Microstructure

Discussion (same discussion as defined in “section A scope”): It should be investigated what differences are observed in TiCp grade 1 and Grade 2 for SLM and EBM. Also the effect of heat treatment should be properly investigated and results of the investigations should be used as input for the standard. *(Microstructures and Mechanical Properties of Ti6Al4V Parts Fabricated by Selective Laser Melting and Electron Beam Melting)*

K. Mechanical properties

If traditional minimum requirements from ISO 5832-2:1999(E) / ASTM F67 are used with heading information similar to ASTM F3001-12 the table could contain following requirements:

Grade	Condition/ classificcation	Tensile Strength MPa *X* and *Y* Directions Minimum requirement	Tensile Strength MPA Z Direction Minimum requirement	Yield Strength at 0.2 % Offset MPa *X* and *Y* Directions Minimum requirement	Yield Strength at 0.2 % Offset MPa *Z* Direction Minimum requirement	Elongation in 5 cm or 4D(%) *X* and *Y* Direction Minimum requirement	Elongation in 5 cm or 4D (%) *Z* Direction Minimum requirement	Reduced Area *X* and *Y* Direction Minimum requirement	Reduced Area Z Direction Minimum requirement
1	A,B,C,D	240	240	170	170	24	24	30	30
2	A,B,C,D	345	345	275	275	20	20	30	30

The mechanical properties of SLM TiCp grade 1 exhibit significantly higher strength values than conventional pieces in grade 1 material. This is due to the rapid solidification rates in the SLM process, which lead to a very fine microstructure as compared to cast or forged products.

Discussion: Should the standard provide more stringent requirements than traditional processes as casting and forging? Initial information shows that unalloyed titanium grade 1 & 2 provides higher mechanical properties. More study should be conducted to confirm this. Results of that study should be consulted for input in the standard.

Our recommendation is that there should be a table providing mechanical properties for each grade as shown above and for each classification. The information can be provided in one table or in different tables. Mechanical properties data should come from proper study on TiCp characteristics with SLM / EBM.

L. Thermal processes

The thermal processes required as described under section D, shall be either decided by the supplier or agreed upon between the purchaser and the supplier.
Either supplier specific processes or heat treat standards can be used. It is crucial that the reported chemical composition and mechanical properties of the titanium material are measured in its finally processed state, meaning, including the agreed heat treatment.

M. HIP

Hip cycle requirements should be documented and products receiving hip should have a certificate providing information of the hip cycle.

Recommendation on HIP Cycle
Process components under inert atmosphere at not less than 1000 bar within the range 895 to 955°C, hold at the selected temperature for 2 to 4 h. and cool under inert atmosphere to below 425°C.

N. Dimensions and permissible variations.

The standard should give reasoning that there are different options to realize the agreed tolerance such as as-built or machining or other processing.

O. Cleanliness of products

Discussion: Powder bed fusion technology works with fine particles. In medical industries (although Titanium's biocompatibility) these particles could be an unwanted side effect. Some degree of acceptability of cleanliness should be noted either in the standard or it should be agreed upon between the purchaser and component supplier.

Particle release standards could be created to cover this issue.
Existing standard on cleanliness of powder metallurgy parts is:

ISO 28279:2010 Sintered metal materials -- Determination of the level of cleanliness of powder-metallurgy parts

P. **Retests**

To be completed.

Q. **Certification**

A certificate, including - if agreed between purchaser and supplier - a complete test report, shall be provided by the component supplier at the time of shipment stating that the components were manufactured and tested in accordance with this specification.

R. **Quality program**

The purchaser has to decide the requirements for a quality program that may consist of requiring an ISO 9001 or other sector specific QMS or may consist of an individual program to work on.

S. **Supplementary requirements**

To be agreed upon with the purchaser in respect to requirement and tolerance and to applicability.

Density testing
Compressive strength testing
Shear strength testing
Fracture toughness testing
Hardness testing
Surface finish test
First article inspection
Particle release requirements
Corrosion resistance test

References to the relevant sources

1. ISO 5832-2 Implants for surgery - Metallic materials - Unalloyed titanium
2. ASTM F 67 – 06 Standard Specification for Unalloyed Titanium, for Surgical Implant Applications
3. ASTM F3001-13 Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium ELI
4. H.K. Rafi, N.V. Karthik, Haijun Gong, Thomas L. Starr, and Brent E. Stucker, Microstructures and Mechanical Properties of Ti6Al4V Parts Fabricated by Selective Laser Melting and Electron Beam Melting, XXXX, submitted March 1, 2013; in revised form May 23, 2013
5. DATA SHEET No 12 Titanium for Medical Applications www.titaniuminfogroup.co.uk
6. ASM metals handbook volume 4: heat treatment
7. http://www.ife.no/en/ife/departments/materials_and_corrosion_tech/files/facts-and-figures-for-commonly-used-titanium-alloys, p.1-2
8. ISO 28401:2010 Light metals and their alloys -- Titanium and titanium alloys -- Classification and terminology, ISO/TC 79/SC 11, p. 13, 2010 http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=44689
9. ISO 20160:2006 Implants for surgery -- Metallic materials -- Classification of microstructures for alpha+beta titanium alloy bars, ISO/TC 150/SC 1, p. 9, 2009 http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=34097
10. ISO 8080:1985 Aerospace -- Anodic treatment of titanium and titanium alloys -- Sulfuric acid process, ISO/TC 20, p. 2, 2012 http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=15113
11. ISO 4490:2008 Metallic powders -- Determination of flow rate by means of a calibrated funnel (Hall flowmeter), ISO/TC 119/SC 2, p.4, 2013 http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=50688
12. ISO 3252:1999 Powder metallurgy – Vocabulary, ISO/TC 119, p.59, 2010 http://www.iso.org/iso/catalogue_detail.htm?csnumber=26045

13. ISO 3923-1:2008 Metallic powders -- Determination of apparent density -- Part 1: Funnel method, ISO/TC 119/SC 2, p.5, 2012
http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=41716
14. ISO 4491-1:1989 Metallic powders -- Determination of oxygen content by reduction methods -- Part 1: General guidelines, ISO/TC 119/SC 2, p. 3, 2011
http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=10384
15. ISO 4491-4:2013 Metallic powders -- Determination of oxygen content by reduction methods -- Part 4: Total oxygen by reduction-extraction, ISO/TC 119/SC 2, p. 5, 2013
http://www.iso.org/iso/catalogue_detail.htm?csnumber=61879
16. ISO 22961:2008 Titanium and titanium alloys -- Determination of iron -- Atomic absorption spectrometry, ISO/TC 79/SC 11, p. 7, 2012
http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=41253
17. ISO 6892-1 Metallic materials - Tensile testing - Part 1 Method of test at room temperature, ISO/TC 164/SC 1, 2013
http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=61856
18. ISO 6506-1:2005 Metallic materials -- Brinell hardness test -- Part 1: Test method, ISO/TC 164/SC 3, p. 15, 2011
http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=37739
19. ISO 3738-1:1982 Hard metals -- Rockwell hardness test (scale A) -- Part 1: Test method, ISO/TC 119/SC 4, p. 3, 2013
http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=9225
20. ISO 1099:2006 Metallic materials -- Fatigue testing -- Axial force-controlled method, ISO/TC 164/SC 5, p. 21, 2009
http://www.iso.org/iso/catalogue_detail.htm?csnumber=36108
21. ISO 12111:2011 Metallic materials -- Fatigue testing -- Strain-controlled thermomechanical fatigue testing method, ISO/TC 164/SC 5, p. 25, 2011
http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=45583
22. ISO 4883:1978 Hard metals -- Determination of contents of metallic elements by X-ray fluorescence -- Solution method, ISO/TC 119/SC 4, p. 2, 2011
http://www.iso.org/iso/catalogue_detail.htm?csnumber=10876
23. ISO 22963:2008 Titanium and titanium alloys -- Determination of oxygen -- Infrared method after fusion under inert gas, ISO/TC 79/SC 11, p. 6, 2012
http://www.iso.org/iso/catalogue_detail.htm?csnumber=41255

Normalisation guidelines for TiAl6Nb7
Input of SIRRIS

SCOPE OF THIS REPORT

The scope of this report is to study the existing status of Ti6Al7Nb Titanium alloy in the field of additive manufacturing, making some recommendations for future standards. Titanium alloys have been clinically applied since the 1970s when surgical implants were made with the high-strength Ti-6Al-4V alloy. The Ti-6Al-7Nb alloy was introduced into clinical use in the mid-1980s as a substitute for Ti-6Al-4V, since niobium is more biocompatible and cheaper than vanadium. The vanadium oxide VO2, generated by passivation of the metal surface, is thermodynamically unstable and some vanadium could be released in human body and cause toxic effects.

EXISTING STANDARDS FOR Ti6Al7Nb

There are two existing standards for the Ti6Al7Nb titanium alloy. The first one, the American one is the ASTM (ASTM F1295-11) standard and the ISO 5832 which is the global class of standards where the ISO 5832/3 standard specifically refers to the Ti6Al7Nb alloy. Both standards appear to be more applied for the medical applications and aerospace applications.

ISO 5832

This global category of standards introduces nomenclature for metal alloys ranging from titanium alloys (wrought), stainless-steel, Cobalt-chromium-molybdenum casting alloys, and a couple others which are all applied for casting & forging technologies but which do not apply for powder based technologies.

ISO 5832/3

This standard specifies the characteristics of and corresponding tests methods for this wrought titanium alloy for the manufacturing of surgical implants (specified). The different normative references for the testing methods are given in this standard (tensile testing, bend test). The chemical composition of the alloy in the specific measured conditions are given and stated.

Chemical Composition									
Weight %	**Al**	**Nb**	**Ta**	**Fe**	**O**	**C**	**N**	**H**	**Ti**
Titanium 6Al-7Nb	5.5-6.6	6.5-7.5	0.50 max	0.25 max	0.20 max	0.08 max	0.05 max	0.009 max	Bal

The microstructure is defined as well as the expected results of the mechanical properties of this alloy are given in this standard.

Typical Mechanical Properties						
Material	Tensile Strength		Yield Strength		Elongation in 5D (%)	Reduction of Area
	ksi	Mpa	ksi	Mpa		
Titanium 6Al-7Nb	145	1000	131	900	12	35

ASTM F1295-11

This standard includes like the ISO one, the specifications for wrought Ti6Al7Nb alloy and again specifically named as an alloy “for surgical implant applications”.

This specification covers the chemical, mechanical, and metallurgical requirements for wrought annealed, cold worked, or hot rolled Ti6Al7Nb alloy bar and wire to be used in the manufacture of surgical implants. Titanium mill products covered in this specification shall be formed with the conventional forging and rolling equipment found in primary ferrous and nonferrous plants, and may be furnished as descaled or pickled, sandblasted, chemically milled, ground, machined, peeled, polished, or cold drawn. Heat analysis shall conform to the chemical composition requirements prescribed for aluminium, niobium, tantalum, iron, oxygen, carbon, nitrogen, hydrogen, and titanium. The material shall conform to the specified requirements for mechanical properties such as ultimate tensile strength, yield strength, and elongation. A minimum of two tension tests from each lot shall be performed. Special requirements for the microstructure are detailed as well.

ONGOING STANDARDS ABOUT POWDER BED FUSION FOR Ti6Al7Nb

A new ASTM International standard will aid in the continuing acceptance of additive manufacturing processes throughout a variety of industries. The new standard, F2924, Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion, was developed by Subcommittee F42.05 on Materials and Processes. This is currently the only one which exists for metal powder bed fusion technologies. There should be a similar existing standard for the Ti6Al7Nb alloy which is very close to the Ti6Al4V alloy ASTM F2924-12a standard. The scope should be to match the same content and requirements as the ASTM F2924-12a standard.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STANDARDISATION

Since this metal alloy is less famous or used amongst the AM users, the standard should base itself on the existing Ti6Al4V alloy ASTM F2924 standard which already gives clear indications of the powder bed metal. Since this alloy is very close from a mechanical point of view and a metallurgical point of view (wrought) it makes sense to establish very similar standard specifications. The only differences that could exist would be at the level of heat post-treatments on the laser beam technology and which could be very different depending on the part that has to be created.

The specifications in terms of mechanical and metallurgical results of this alloy should be revised in general and applied for additive manufacturing technologies.

Thus the recommendation would be in general to establish similar standard specifications as the existing ASTM F2924 standard for the Ti6Al4V alloy, yet adapt the AM-specific material properties and test methods that can be achieved by powder bed technologies. A specific attention should be given to the post-processing (heat treatments) of this material. A clear distinction should be established between the Electron Beam Melting and the Laser Beam Melting technology in terms of mechanical and metallurgical properties. Since those two classes of technologies are highly different, the material results are very different as well. A specific investigation and comparison between different laser beam melting technologies should be conducted as well since the atmospheric control (Argon gas) is very process dependent (manufacturer dependent) and so are the metallurgical & mechanical properties of the parts coming out of those laser beam technologies.

A clear match should as well exist between ISO and ASTM standards concerning the test methods for metals. Experts establishing the standards for the Ti6Al7Nb titanium alloy should definitely contact Fraunhofer Institut IWU experts in Chemnitz, Germany since they already developed this material on a Concept Laser machine (laser beam technology). This group will have extensive knowledge about thermal stress relieve concerning this alloy. (Contact: Dr. Bernhard Mueller, Fraunhofer IW, phone +49 351 4772-2136, mail: Bernhard.muller@iwu.fraunhofer.de).

CONTENT OF FUTURE STANDARD FOR Powder bed fusion for Ti6Al7Nb

This standard should include the following content:

A. Scope

The standard describes general requirements of Ti6Al7Nb titanium alloy to be processed under powder bed fusion technologies such as laser beam melting and electron beam melting. The scope includes raw material-feedstock of Ti6Al7Nb and characteristics of processed parts in order to ensure acceptable quality of final part (mechanical and metallurgical properties as well as the test methods and requirements on post treatments).

B. Terminology

Scope: ASTM F2924-12a

The terminology should include the definitions given in ASTM F2924-12a standard.

C. Classification

Scope: ASTM F2924-12a

The classification should include the definitions given in ASTM F2924-12a standard.

D. Manufacturing plan

Scope: ASTM F2924-12a

The manufacturing plan should include the definitions given in ASTM F2924-12a standard.

E. Feedstock and recycling influence

Scope: ASTM F2924-12a

The feedstock and recycling influence should include the definitions given in ASTM F2924-12a standard.

F. Process

Scope: ASTM F2924-12a

The process should include the definitions given in ASTM F2924-12a standard.

G. Chemical composition

Scope: ASTM F2924-12a

The chemical composition should include the definitions given in ASTM F2924-12a standard and comply as much as possible as the ASTM F1295-11 standard and the ISO 5832-3 standard.

H. Microstructure

Scope: ASTM F2924-12a

However, since there hasn't been any Ti6Al7Nb titanium alloy being processed on EBM technologies so far to my knowledge, testing should be done in order to define and give the input for the future standard. Since there are very few users of Ti6Al7Nb titanium alloy on laser beam systems, specific care and attention should be given to compare the microstructures of parts coming out of the different laser based systems. A comparison should be conducted between the different results and discussed. Microstructure and mechanical properties would require more maturity and investigation.

I. Mechanical properties

Scope: ASTM F2924-12a

Similar to microstructure! No EBM machines have been using Ti6Al7Nb. There is a knowledge gap for this material concerning mechanical properties, especially fatigue properties. Further investigation is required. Similar is necessary for laser beam process.

J. Stress relief

Scope: ASTM F2924-12a

Since there is no stress relief required for EBM processed parts, requirements should follow the ASTM F2924-12a standards for laser beam technologies. Further investigation is however required for laser based systems which are very dependent on the gas flow direction and composition that is used on the different systems. The stress relief will be highly different on this material compared to the defined and described Ti6Al4V alloy in the ASTM F2924-12a. Further information should be available at the given contact from the Fraunhofer IWU in Germany.

K. HIP

Scope: ASTM F2924-12a

The HIP post-treatment should include the specifications given in ASTM F2924-12a standard.

L. Dimensions and permissible variations

Scope: ASTM F2924-12a

The dimensions and permissible variation should include the specification given in ASTM F2924-12a standard.

M. Retests

Scope: ASTM F2924-12a

The retests procedures should include the specifications given in ASTM F2924-12a standard.

N. Certification

Scope: ASTM F2924-12a

The certification should include the specifications given in ASTM F2924-12a standard.

O. Quality program

Scope: ASTM F2924-12a

The quality program is highly dependent on the purchaser and the application field and should include the specifications given in ASTM F2924-12a standard.

P. Supplementary requirements to be agreed upon with the purchaser in respect to requirement and tolerance and to applicability

Scope: ASTM F2924-12a

References to the relevant sources:

1. ASTM F2924-12a
2. ISO 5832-3 Implants fur Surgery – Metallic Materials – Part 3: Wrought T6Al4V alloy
3. ASTM F1295-11: Standard Specification for Wrought Ti6Al7Nb alloy for surgical implant applications
4. ISO/ASTM52921-13. Standard Terminology for Additive Manufacturing Coordinate Systems and Test Methodologies
5. ASTM F136-13: Standard Specification for Wrought Ti6Al4V-ELI alloy for surgical implant applications
6. ASTM F136-13: Standard Specification for Wrought Ti6Al4V alloy for surgical implant applications
7. NISTIR 7847 : "Mechanical Properties Testing for Metal Parts Made via Additive Manufacturing: A Review of the State of the Art of Mechanical Property Testing" by John Slotwinski, April Cooke, Shawn Moylan
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10. ASTM F136
11. ASTM F1295,
12. ASTM F1472

Normalisation guidelines for Nickel-base alloys
Input of ENISE

SCOPE OF THIS REPORT

The scope of this report is to study the current standardization status of diverse Ni base alloys (examples are Inconel 625, Inconel 718, Nickelalloy HX and other) and provide comprehensive recommendations for the future standards in additive manufacturing employing these and similar materials. This group of alloys is used for their outstanding corrosion and high temperature resistance in the energy, power, chemical and petrochemical industries.
The term "superalloy" is applied to alloys which have outstanding high temperature strength and oxidation resistance. The nickel-based superalloys contain carefully balanced alloying additions of chromium, cobalt, aluminum, titanium and other elements. Often components are produced by carefully controlled solidification in order to get an optimum directionally solidified or even single crystal structure. These components can have strengths at 1000°C which exceed that of ordinary steels at room temperature. They are essential in the hottest parts of gas turbines both for power generation and aircraft.

EXISTING STANDARDS FOR Ni-base ALLOYS

There are several normalization documents that determine properties of different Ni-base alloys products.

ASTM B443 developed by Subcommittee B02.07
This specification covers rolled nickel-chromium-molybdenum-columbium alloy (UNS No. N06625) and nickel-chromium-molybdenum-silicon alloy (UNS No. N06219) plates, sheets, and strips. N06625 alloys shall be furnished in two grades of different heat treatment conditions, namely: Grade 1 (annealed); and Grade 2 (solution annealed). N06219 alloys, on the other hand, shall be furnished in solution annealed condition only. Materials shall be sampled prepared, and tested accordingly to examine their conformance to dimensional (thickness, weight, width, diameter, length, straightness, edges, squareness, and flatness), mechanical (tensile and yield strengths, and elongation), and chemical composition requirements.

ASTM B444 (B02.07)
This specification covers UNS N06625 and UNS N06852 nickel-chromium-molybdenum-columbium alloys and UNS N06219 nickel-chromium-molybdenum-silicon alloy in the form of cold-worked seamless pipe and tube. UNS N06625 products are furnished in annealed Grade 1 and solution annealed Grade 2 while UNS N06219 and UNS N06852 are in solution annealed condition only. Chemical testing shall be performed on each type of material and shall conform to the chemical composition limits specified for carbon, manganese, silicon, phosphorus, sulfur, chromium, tantalum, columbium, cobalt, molybdenum, iron, aluminum, titanium, copper, and nickel. The material shall undergo tensile testing and shall conform to the required room temperature tensile properties like tensile strength, yield strength, and elongation depending on the heat treatment used and including small diameter and light-walled tubing. Each pipe or tube shall undergo hydrostatic testing and shall conform to the allowable fiber stress and also be examined with a nondestructive electric test as prescribed.

ASTM B446 (B02.07)
This specification covers nickel-chromium-molybdenum-columbium (UNS N06625), nickel-chromium-molybdenum-silicon alloy (UNS N06219), and nickel-chromium-molybdenum-tungsten alloy (UNS N06650) in the form of hot-worked rod and bar and cold-worked rod. The matreial shall conform to the required chemical composition for carbon, manganese, silicon, phosphorus, sulfur, chromium, columbium, tantalum, cobalt, molybdenum, iorn, aluminum, titanium, copper, nickel, tungsten, and nitrogen. The materials shall conform to the the heat treatment and room temperature tensile properties such as tensile strength, yield strength, and elongation. Dimensions of the alloys such as diameter, thickness, or width, length and straightness shall also be determined.

ASTM B637 (B02.07)
This specification covers hot- and cold-worked precipitation-hardenable nickel alloy rod, bar, forgings, and forging stock for high-temperature service. Chemical analysis shall be performed on the alloy and shall conform to the chemical composition requirement in carbon, manganese, silicon, phosphorus, sulfur,

chromium, cobalt, molybdenum, columbium, tantalum, titanium, aluminum, zirconium, boron, iron, copper, and nickel. The material shall follow recommended annealing treatment, solution treatment, stabilizing treatment, and precipitation hardening treatment. Tension testing, hardness testing and stress-rupture testing shall be performed on the material and shall comply to the required tensile strength, yield strength, elongation, reduction in area, and Brinell hardness.

ISO 9722:1992 - Nickel and nickel alloys -- Composition and forms of wrought products
Lists the chemical composition and density of wrought nickel and nickel alloys and commercially available wrought products. Annex A contains a list of ISO methods of analysis. The definitions for nickel and nickel alloys in ISO 6372-1 and for wrought products in ISO 6372-3 apply.

ASTM B880 (B02.07)
This specification details the limits of variation for determining the chemical check analysis limits of cast or wrought nickel, nickel alloy and cobalt alloy parts and/or supplied material.

Some normalisation documents treat also relevant items, namely:

ISO 6372:1989 (Parts 1-3) Nickel and nickel alloys - Terms and definitions: Materials, Refinery products, Wrought products and castings.

ASTM E8/E8M Standard Test Methods for Tension Testing of Metallic Materials
These test methods cover the tension testing of metallic materials in any form at room temperature, specifically, the methods of determination of yield strength, yield point elongation, tensile strength, elongation, and reduction of area.

ASTM E6 Standard Terminology Relating to Methods of Mechanical Testing
This terminology covers the principal terms relating to methods of mechanical testing of solids. The general definitions are restricted and interpreted, when necessary, to make them particularly applicable and practicable for use in standards requiring or relating to mechanical tests. These definitions are published to encourage uniformity of terminology in product specifications.
Terms relating to fatigue and fracture testing are defined in Terminology E1823.

ONGOING STANDARDS ABOUT POWDER BED FUSION OF Ni-base ALLOYS
A new ASTM International standard will aid in the continuing acceptance of additive manufacturing processes throughout a variety of industries. The following Work Items are currently under development by ASTM.

ASTM WK33776 - New Specification for Additive Manufacturing Nickel Alloy (UNS N07718) with Powder Bed Fusion developed by Subcommittee F42.05 Committee F42
Scope 1.1 Specification covers additively manufactured nickel alloy UNS N07718 components using full melt powder bed fusion such as electron beam melting and laser melting. The components produced by these processes are used typically in applications that require mechanical properties similar to machined forgings and wrought products. Components manufactured to this specification are often, but not necessarily, post processed via machining, grinding, EDM, polishing, etc. to achieve desired surface finish and critical dimensions.

1.2 This specification is intended for use of purchasers and /or producers of additively manufactured nickel UNS N07718 components for defining the requirements and assuring component properties. 1.3 Users are advised to use the specification as a basis for obtaining components which will meet the minimum acceptance requirements established and revised by consensus of the members of the committee.

1.4 User requirements considered more stringent may be met by the addition to the purchase order of one or more supplementary requirements, which may include, but are not limited to, those listed in supplementary section S1 through S10.

ASTM WK33658 - New Specification for Additive Manufacturing Nickel Alloy (UNS N06625) with Powder Bed Fusion developed by Subcommittee F42.05 Committee F42

1.1 This specification covers additively manufactured nickel alloy UNS N06625 components using full melt powder bed fusion such as electron beam melting and laser melting. The components produced by these processes are used typically in applications that require mechanical properties similar to machined forgings and wrought products. Components manufactured to this specification are often, but not necessarily, post processed via machining, grinding, EDM, polishing, etc. to achieve desired surface finish and critical dimensions.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STANDARDISATION

CONTENT OF FUTURE STANDARD FOR Powder bed fusion of Ni-base alloys

This standard should include the following content:

A. Scope

The standard describes general requirements of Ni-base alloys titanium alloy to be processed under powder bed fusion technologies such as laser beam melting and electron beam melting. The scope includes raw material-feedstock of Ni-base alloys and characteristics of processed parts in order to ensure acceptable quality of final part (mechanical and metallurgical properties as well as the test methods and requirements on post treatments).

B. Terminology

The terminology should extend the definitions given in ISO 6372:1989 (Parts 1-3) standard.

C. Classification

The classification should extend the definitions given in ISO 6372:1989 (Parts 1-3) standard.

D. Chemical composition

Scope: ASTM F2924-12a

The chemical composition should include the definitions given in ASTM F2924-12a standard and comply as much as possible as the ASTM F1295-11 standard and the ISO 5832-3 standard.

E. Manufacturing plan

The manufacturing plan should be identified following the results of scientific research works relating manufacturing procedure with the resulting product properties.

F. Feedstock and recycling management

G. Process

The standard shall contain the typical process parameters recommended for each material and for each technology (laser melting or EBM).

H. Microstructure

Dependent upon material.

I. Stress relief

Dependent upon material.

J. Certification

Determined by existing standards.

K Quality program

To be determined.

L. <u>Supplementary requirements to be agreed upon with the purchaser in respect to requirement and tolerance and to applicability</u>

References to the relevant sources:

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Annex II Criteria for test laboratories (ISO/IEC 17025)

INTERNATIONAL STANDARD

ISO/IEC 17025

Second edition
2005-05-15

General requirements for the competence of testing and calibration laboratories

Exigences générales concernant la compétence des laboratoires d'étalonnages et d'essais

Reference number
ISO/IEC 17025:2005(E)

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ISO/TC 261 N 66

INTERNATIONAL STANDARD

ISO/ASTM 52915

First edition
2013-06-01

Standard specification for additive manufacturing file format (AMF) Version 1.1

Spécification normalisée pour le format de fichier pour la fabrication additive (AMF) Version 1.1

Reference number
ISO/ASTM 52915:2013(E)

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