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EMERALD

The Education, Scholarships, Apprenticeships and Youth Entrepreneurship

EUROPEAN NETWORK FOR 3D PRINTING OF BIOMIMETIC MECHATRONIC SYSTEMS

E-toolkit – New materials used for the developed biomimetic mechatronic systems

Project Title	**European network for 3D printing of biomimetic mechatronic systems** **21-COP-0019**
Output	**IO2 - EMERALD e-toolkit manual for digital learning in producing biomimetic manufacturing method**
Module	**Database used for the smart (intelligent) materials properties**
Date of Delivery	**January 2023**
Authors	**Diana BĂILĂ, PUB**
Version	**FINAL VARIANT, *27.01.2023***

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Total Materia used for determination of the materials properties.

1 Total Materia database – Quick search for alloys

Total Materia is the world's most comprehensive materials database, having more than 20,000,000 property records for over 450,000 metallic and non-metallic materials presented in 26 languages. This database is world class quality, service and support, being trusted in over 160 countries, the smallest companies to global industry leaders all receive our complete specialist technical support. Total Materia is proprietary algorithms for the identification of unknown materials, using composition data from analytical sources, find matching materials, property data and equivalents in just seconds. This database is the largest single collection of advanced property data on the planet, having more than 150,000 materials with stress strain, fatigue data and much more for the design community, being a free page. This database permits lightning fast access for finding and comparing equivalent materials, existing international cross-references for 450,000 materials from 74 standards providing over 15,000,000 material connections.

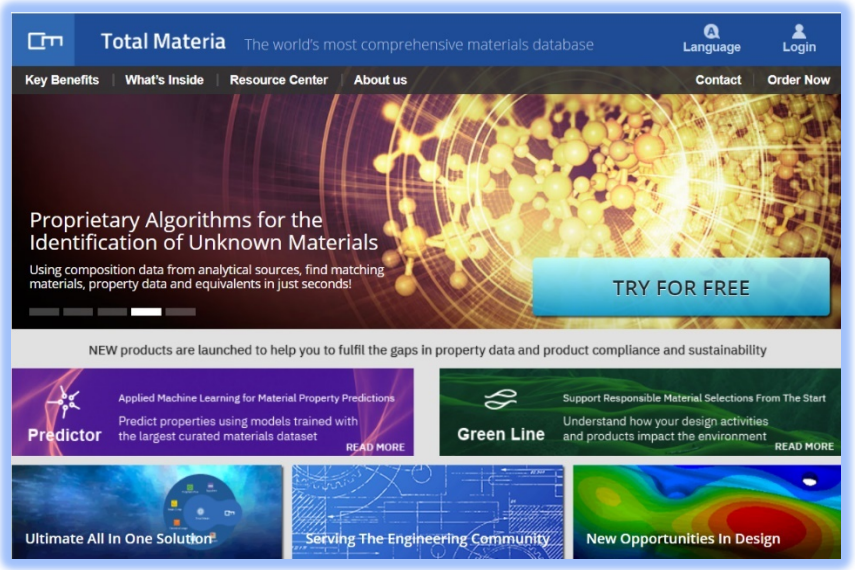

Fig.1. Total Materia database

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Total Materia database help solve diverse engineering challenges from the simplest to the complex, being used in: medicine industry, aerospace industry, energy industry, automotive industry, machinery industry, engineering industry, diversified.

By example, for the alloy Ti6Al4 V, we want to know the chemical composition and the mechanical properties, and we click on Advanced Search, as in the Figure 2.

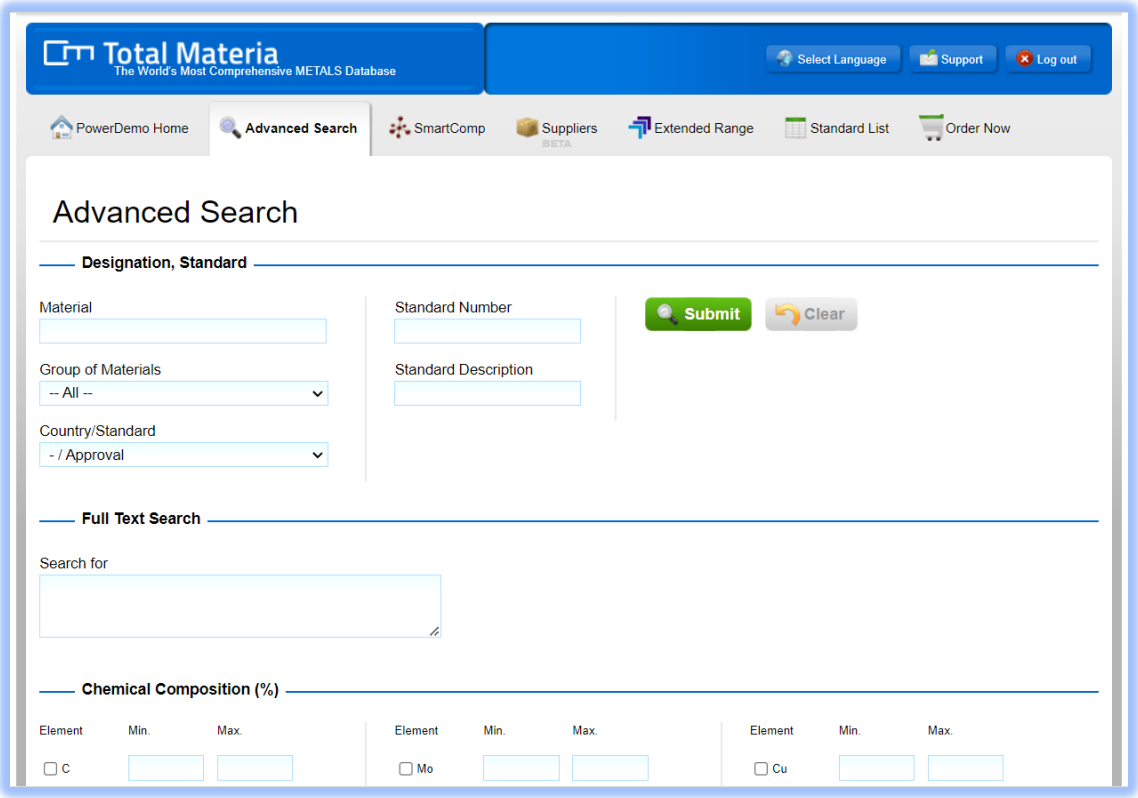

Fig.2. Advanced Search

In the figure 3, it is presented the choice of the standard in function of the country and group of materials.

It was choosing the alloy Ti6Al4V, making part of Titanium materials and was choose European Union standard, as in Figure 3. It must specify the material type, as example Bulk Materials, in Figure 4.

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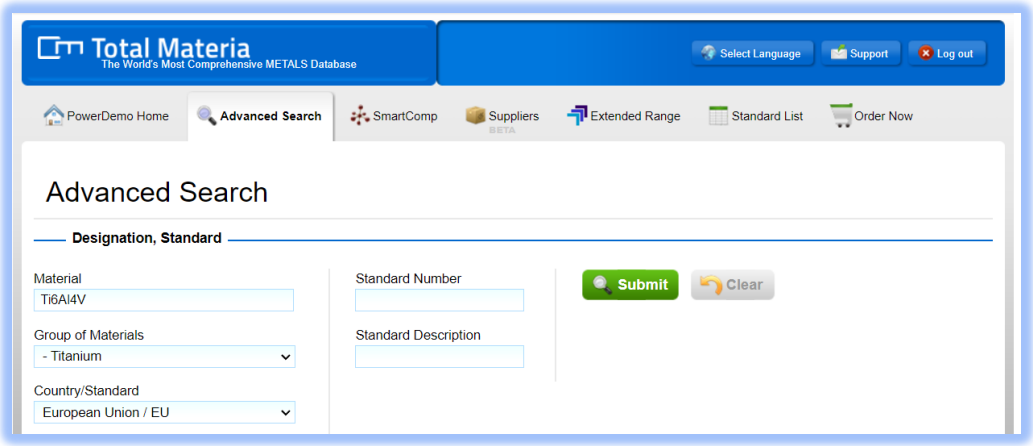

Fig.3. European Union standard choice

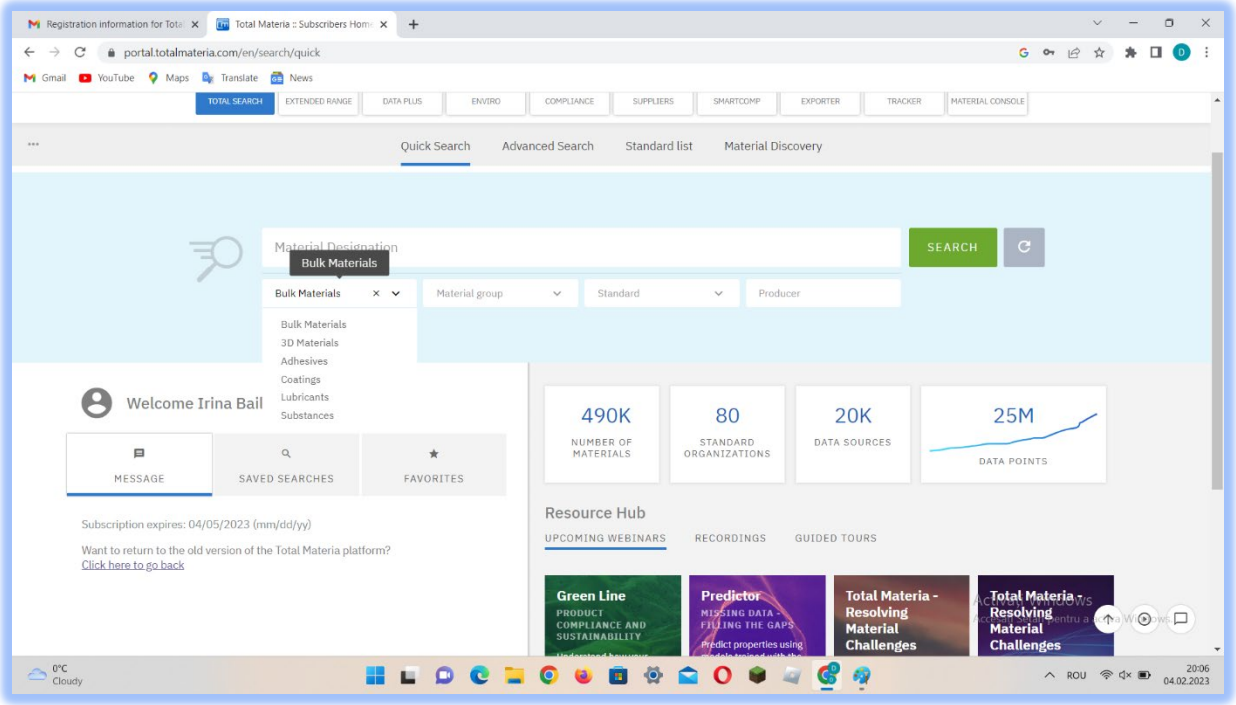

Fig.4. Material type

In figure 5, it is specifying the material group and in this case, nonferrous alloys and European standard choice, as in figure 6.

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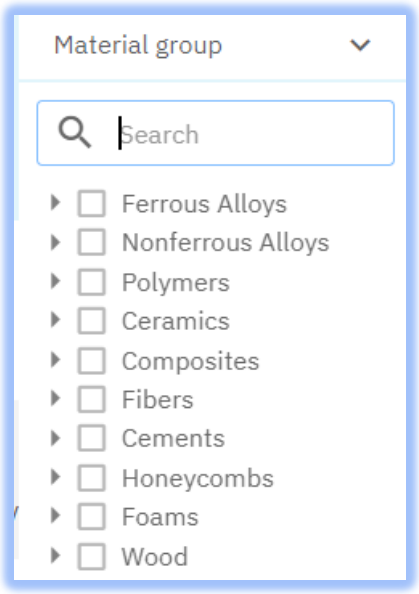

Fig.5. Material group

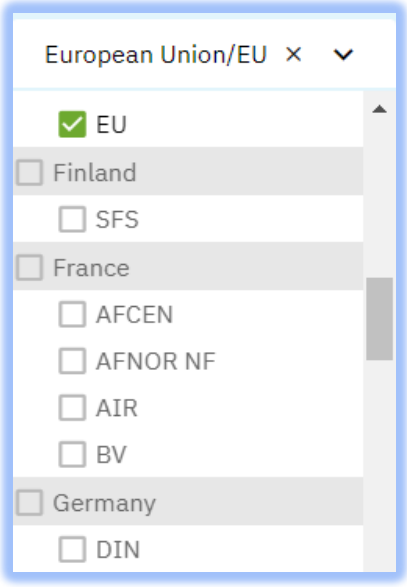

Fig.6. European standard choice

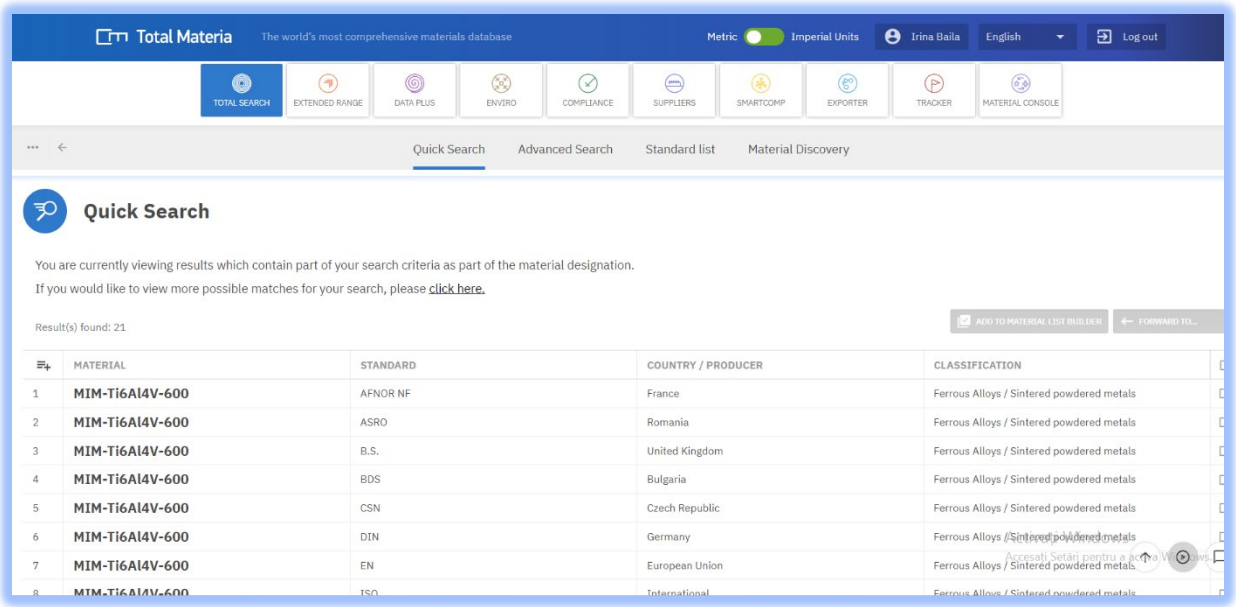

Fig.7. Different Ti6Al4V producers

When we give a quick search, as in figure 7, are presented different Ti6Al4V producers from different countries and using different standards.

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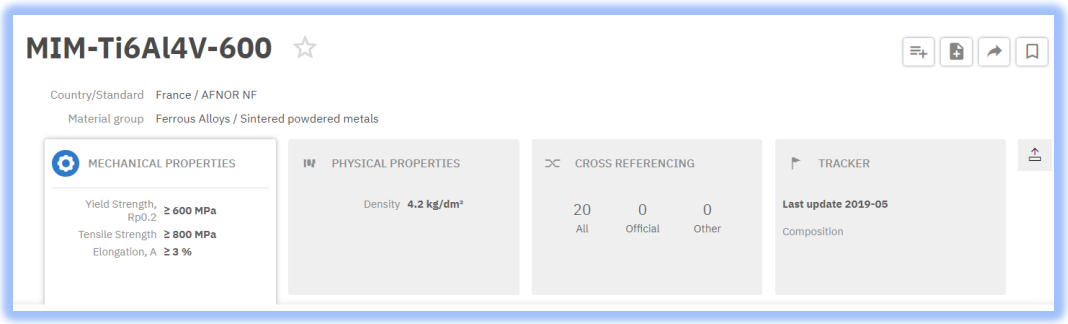

Fig.8. Ti6Al4V standard Fr AFNOR NF-Mechanical properties

The results it is the mechanical properties of the alloy Ti6Al4V, conforming of FR AFNOR NF standard, as in figure 8 and figure 9.

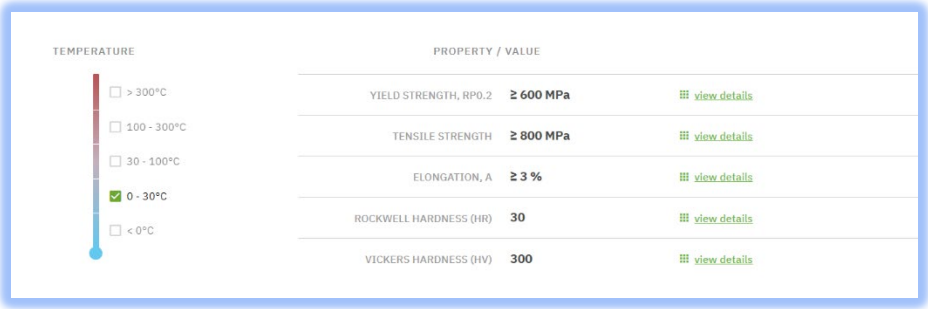

Fig.9. Mechanical properties Ti6Al4V at the temperature between 0-30°C

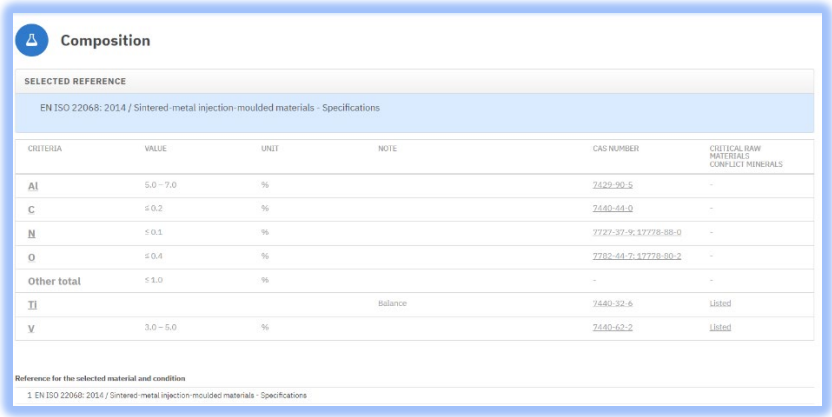

Fig.10. Chemical composition of Ti6Al4V

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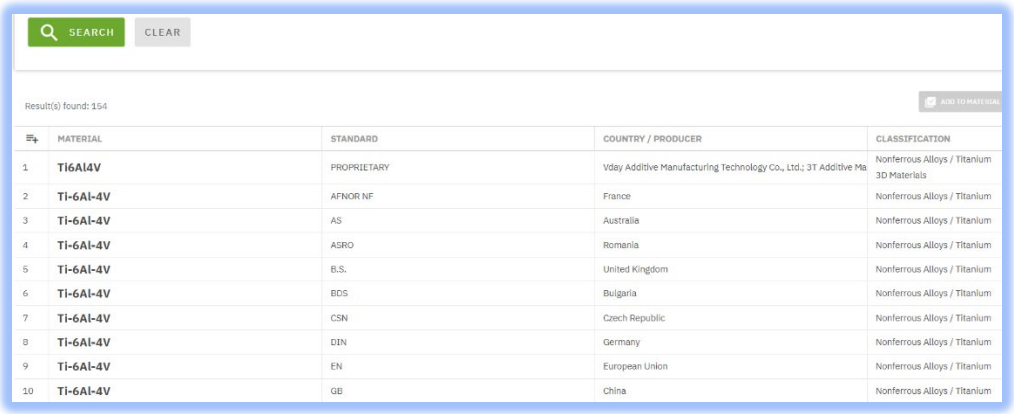
In figure 9, the database gives us all information about the mechanical properties of the alloy Ti6Al4V in function of the temperature used in the process where it is used this material.
In figure 10, the database shows us the chemical composition of the alloy Ti6Al4V.

2. Total Materia database – Advanced Research for alloys

In the case of Advanced Research, by example for the Ti6Al4V, producer Vday Additive Manufacturing Technology Co., it is given the classification of different Ti alloys producers, as in figure 11.



	MATERIAL	STANDARD	COUNTRY / PRODUCER	CLASSIFICATION
1	Ti6Al4V	PROPRIETARY	Vday Additive Manufacturing Technology Co., Ltd.; 3T Additive Ma	Nonferrous Alloys / Titanium 3D Materials
2	Ti-6Al-4V	AFNOR NF	France	Nonferrous Alloys / Titanium
3	Ti-6Al-4V	AS	Australia	Nonferrous Alloys / Titanium
4	Ti-6Al-4V	ASRO	Romania	Nonferrous Alloys / Titanium
5	Ti-6Al-4V	B.S.	United Kingdom	Nonferrous Alloys / Titanium
6	Ti-6Al-4V	BDS	Bulgaria	Nonferrous Alloys / Titanium
7	Ti-6Al-4V	CSN	Czech Republic	Nonferrous Alloys / Titanium
8	Ti-6Al-4V	DIN	Germany	Nonferrous Alloys / Titanium
9	Ti-6Al-4V	EN	European Union	Nonferrous Alloys / Titanium
10	Ti-6Al-4V	GB	China	Nonferrous Alloys / Titanium

Fig.11. Ti6Al4V alloy used in Additive Manufacturing

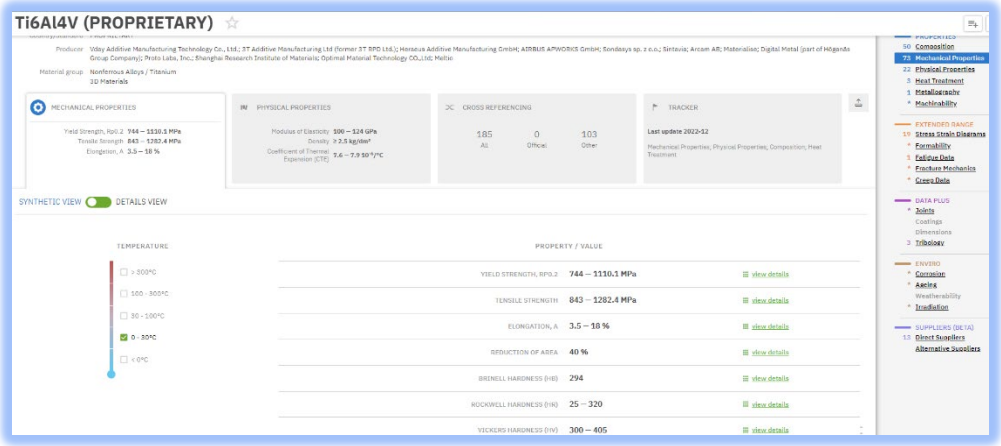


Fig.12. Mechanical properties of Ti6Al4V used in Additive Manufacturing

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In the figure 12, are presented the mechanical properties of Ti6Al4V used in Additive Manufacturing, for different temperature domains. The chemical composition of Ti6Al4V used in Additive Manufacturing is given in the figure 13. In the figure 14, the physical properties of Ti6Al4V used in Additive Manufacturing, for different temperature domains.

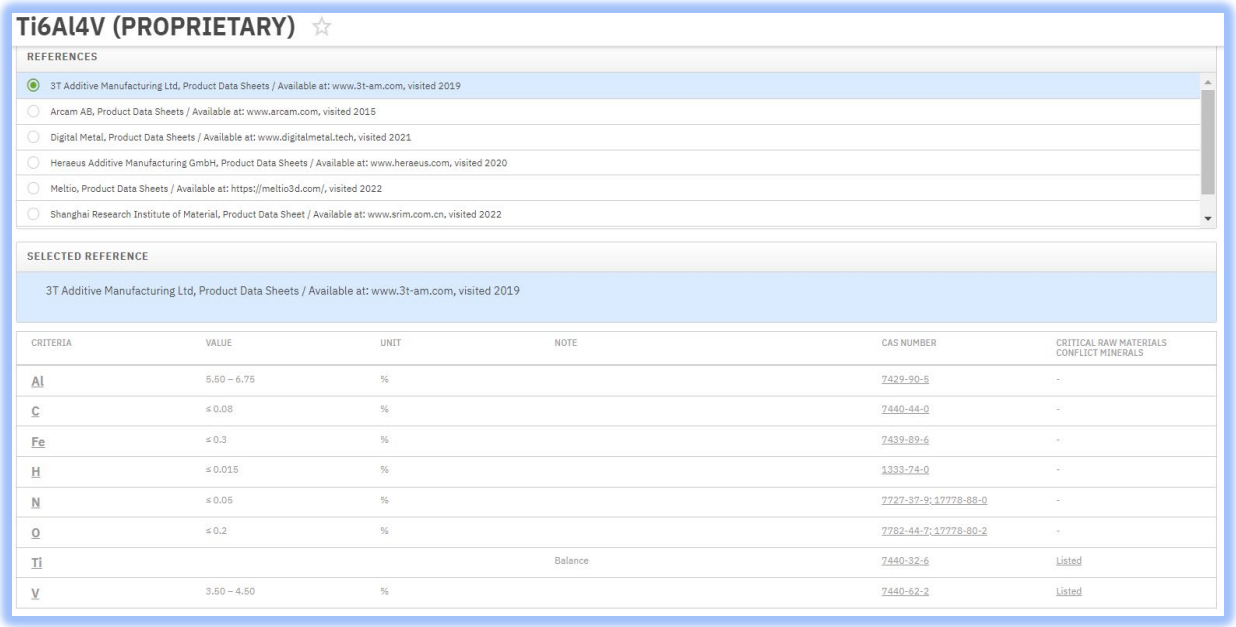

Fig.13. Chemical composition of Ti6Al4V used in Additive Manufacturing

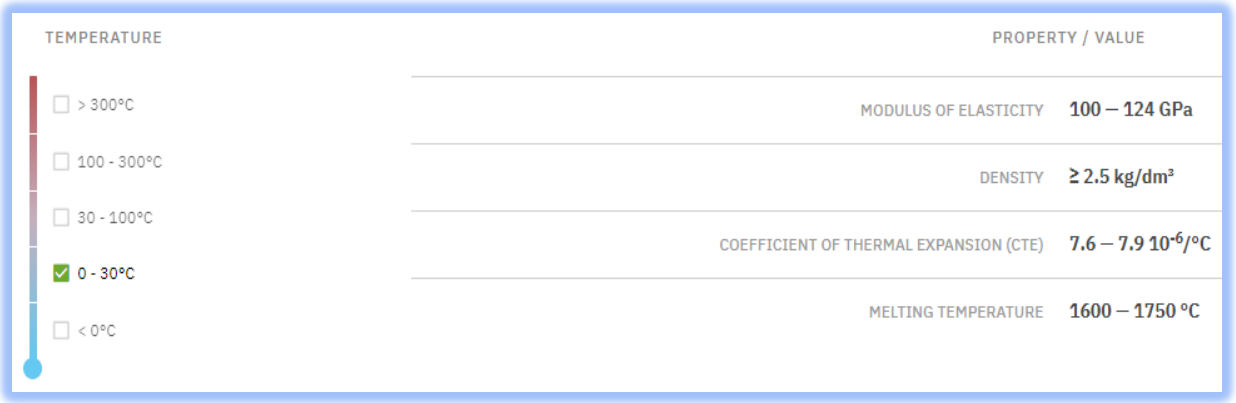

Fig.14. Physical properties of Ti6Al4V used in Additive Manufacturing

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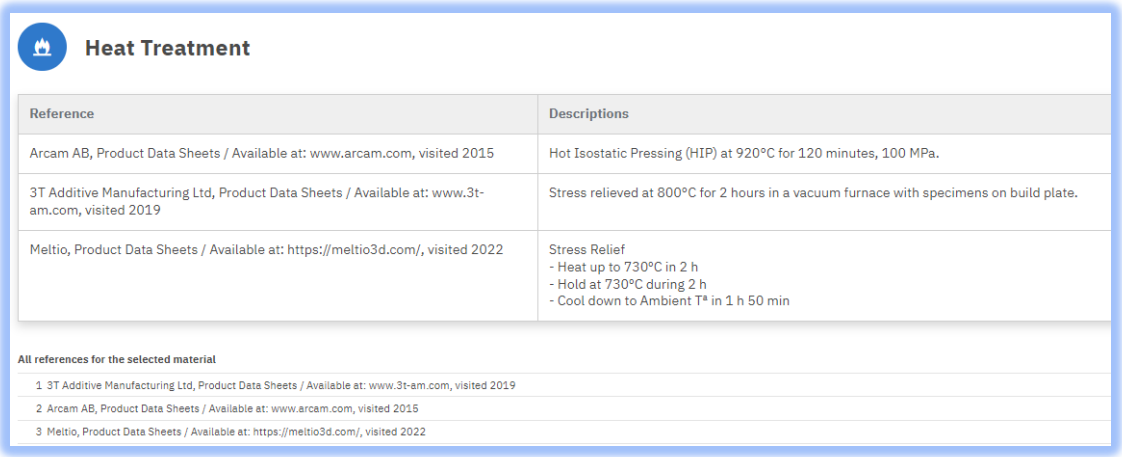

Heat Treatment

Reference	Descriptions
Arcam AB, Product Data Sheets / Available at: www.arcam.com, visited 2015	Hot Isostatic Pressing (HIP) at 920°C for 120 minutes, 100 MPa.
3T Additive Manufacturing Ltd, Product Data Sheets / Available at: www.3t-am.com, visited 2019	Stress relieved at 800°C for 2 hours in a vacuum furnace with specimens on build plate.
Meltio, Product Data Sheets / Available at: https://meltio3d.com/, visited 2022	Stress Relief - Heat up to 730°C in 2 h - Hold at 730°C during 2 h - Cool down to Ambient T° in 1 h 50 min

All references for the selected material

1 3T Additive Manufacturing Ltd, Product Data Sheets / Available at: www.3t-am.com, visited 2019
2 Arcam AB, Product Data Sheets / Available at: www.arcam.com, visited 2015
3 Meltio, Product Data Sheets / Available at: https://meltio3d.com/, visited 2022

Fig.15. Heat treatment used for the alloy Ti6Al4V used in Additive Manufacturing

The database gives us details concerning the heat treatment used for the alloy Ti6Al4V used in Additive Manufacturing, as in the figure 15.

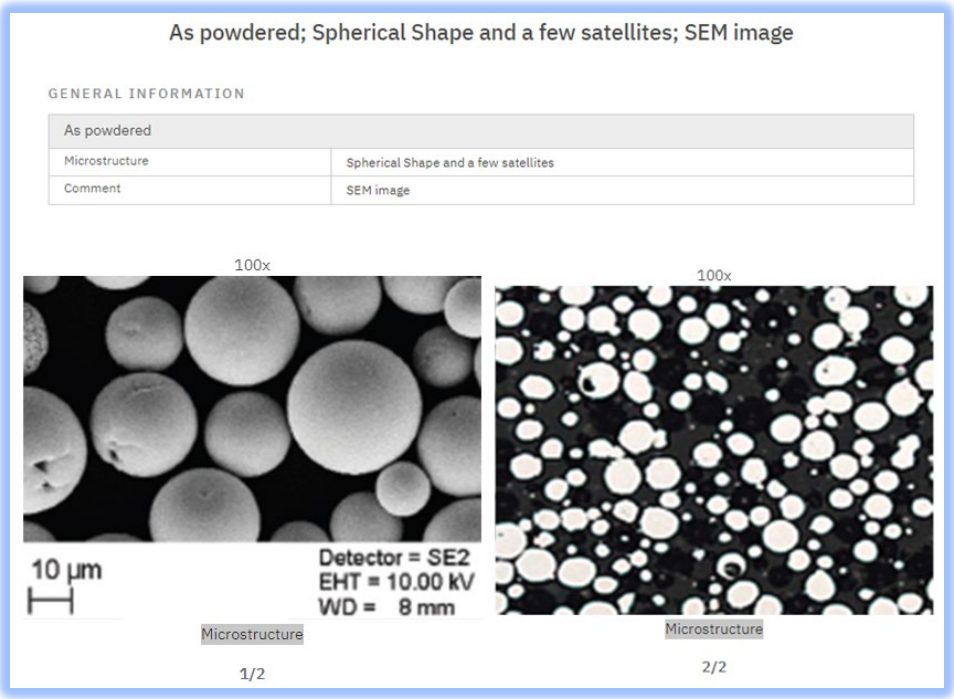

Fig.16. Metallography details for Ti6Al4V powders used in Additive Manufacturing

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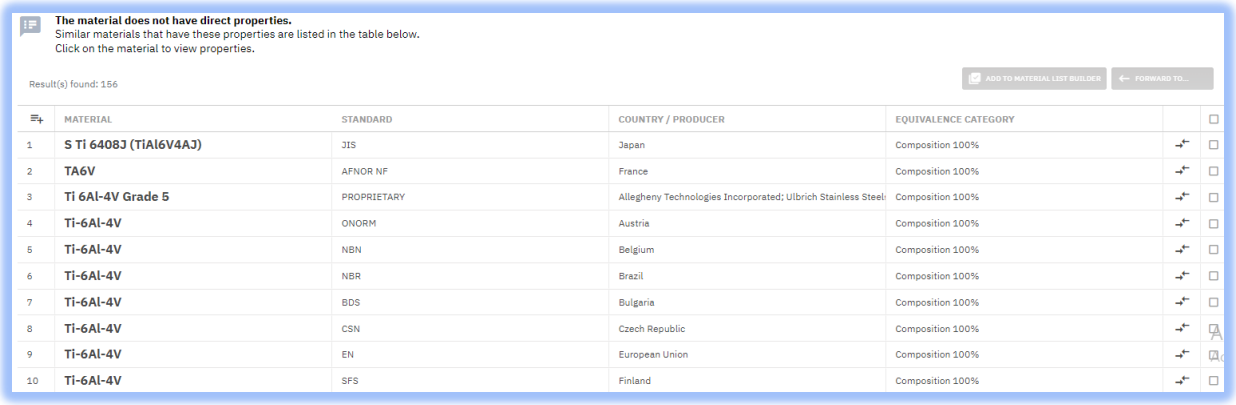
Total Materia gives us details concerning the metallography of the alloy Ti6Al4V used in Additive Manufacturing, as in the figure 16 and the tribology is given in figure 18. In figure 17 are presented the similar materials with the same composition existing on the market.

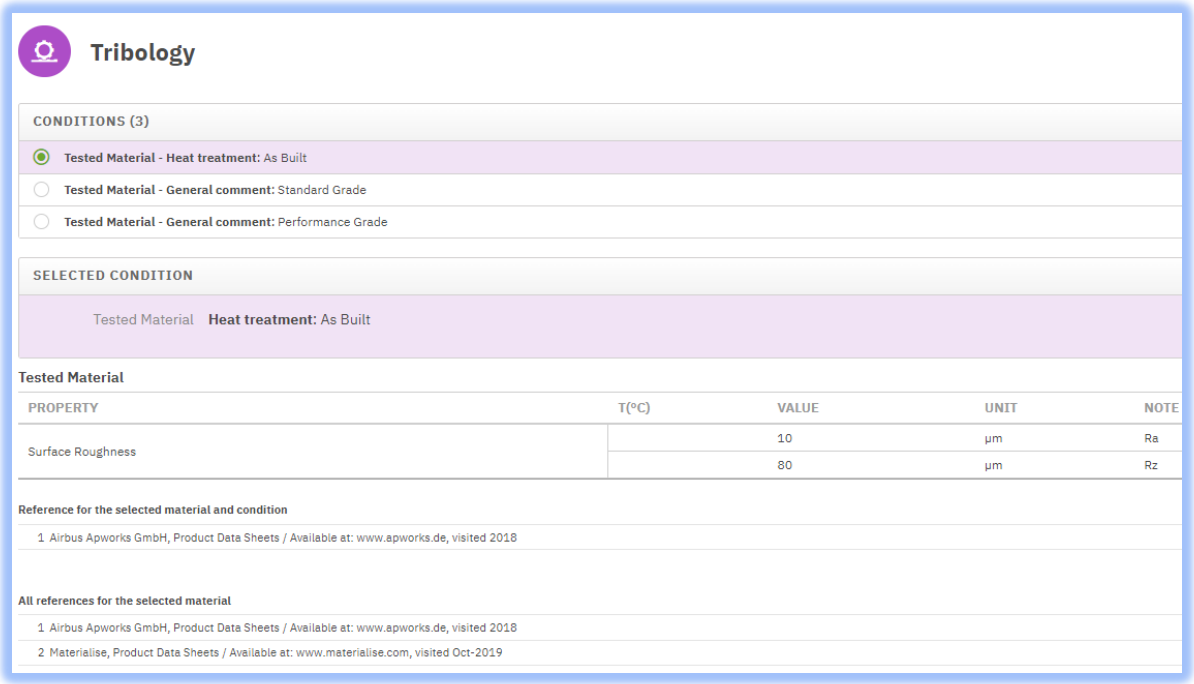


The material does not have direct properties.
Similar materials that have these properties are listed in the table below.
Click on the material to view properties.

Result(s) found: 156

	MATERIAL	STANDARD	COUNTRY / PRODUCER	EQUIVALENCE CATEGORY
1	S Ti 6408J (TiAl6V4AJ)	JIS	Japan	Composition 100%
2	TA6V	AFNOR NF	France	Composition 100%
3	Ti 6Al-4V Grade 5	PROPRIETARY	Allegheny Technologies Incorporated; Ulbrich Stainless Steel	Composition 100%
4	Ti-6Al-4V	ONORM	Austria	Composition 100%
5	Ti-6Al-4V	NBN	Belgium	Composition 100%
6	Ti-6Al-4V	NBR	Brazil	Composition 100%
7	Ti-6Al-4V	BDS	Bulgaria	Composition 100%
8	Ti-6Al-4V	CSN	Czech Republic	Composition 100%
9	Ti-6Al-4V	EN	European Union	Composition 100%
10	Ti-6Al-4V	SFS	Finland	Composition 100%

Fig.17. Similar Materials with the same composition existing on the market



Tribology

CONDITIONS (3)

- **Tested Material - Heat treatment:** As Built
- **Tested Material - General comment:** Standard Grade
- **Tested Material - General comment:** Performance Grade

SELECTED CONDITION

Tested Material **Heat treatment:** As Built

Tested Material

PROPERTY	T(°C)	VALUE	UNIT	NOTE
Surface Roughness		10	µm	Ra
		80	µm	Rz

Reference for the selected material and condition

1 Airbus Apworks GmbH, Product Data Sheets / Available at: www.apworks.de, visited 2018

All references for the selected material

1 Airbus Apworks GmbH, Product Data Sheets / Available at: www.apworks.de, visited 2018

2 Materialise, Product Data Sheets / Available at: www.materialise.com, visited Oct-2019

Fig.18. Tribology properties of Ti6Al4V used in Additive Manufacturing

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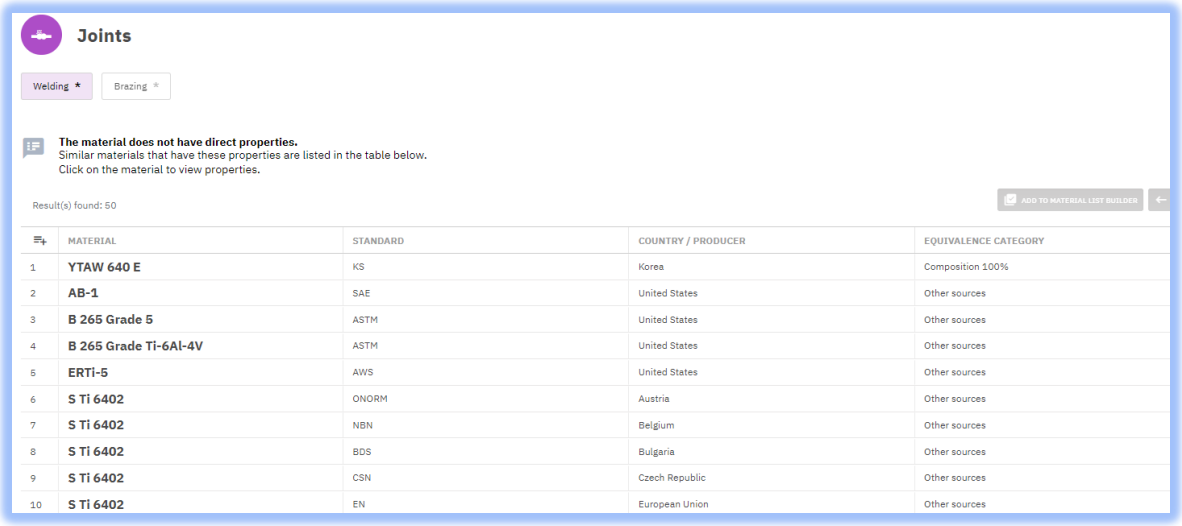
For welding and brazing are given different variants similar alloy of Ti, as in figure 19. In the figure 20, it is presented the stress strain diagram for Ti6Al4V used in Electron Beam Melting (EBM). The fatigue data is given in the figure 21, by ARCAM company.



	MATERIAL	STANDARD	COUNTRY / PRODUCER	EQUIVALENCE CATEGORY
1	YTAW 640 E	KS	Korea	Composition 100%
2	AB-1	SAE	United States	Other sources
3	B 265 Grade 5	ASTM	United States	Other sources
4	B 265 Grade Ti-6Al-4V	ASTM	United States	Other sources
5	ERTi-5	AWS	United States	Other sources
6	S Ti 6402	ONORM	Austria	Other sources
7	S Ti 6402	NBN	Belgium	Other sources
8	S Ti 6402	BDS	Bulgaria	Other sources
9	S Ti 6402	CSN	Czech Republic	Other sources
10	S Ti 6402	EN	European Union	Other sources

Fig.19. Different variants similar alloy of Ti, used in welding and in brazing

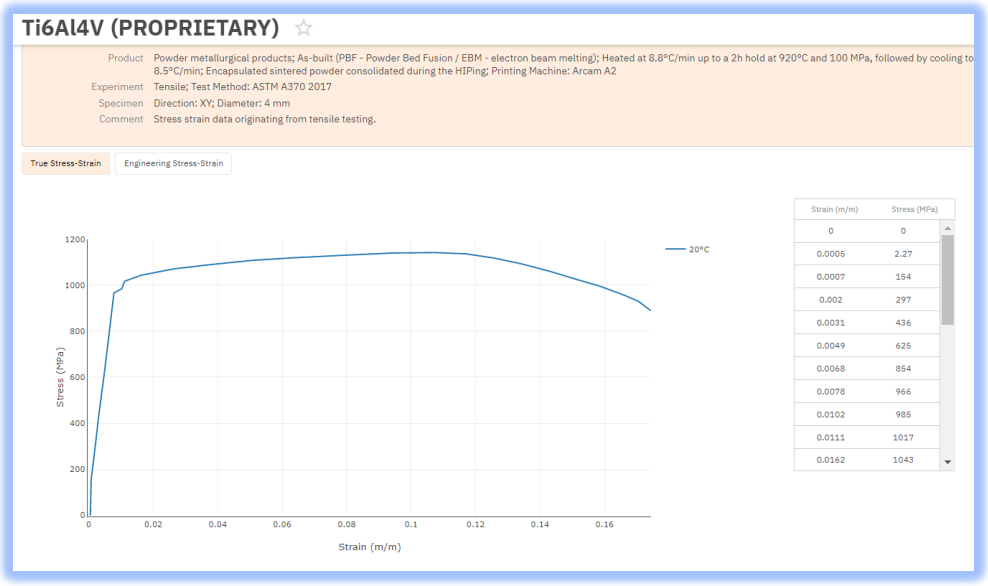


Fig.20. Stress strain diagram for Ti6Al4V used in Electron Beam Melting (EBM)

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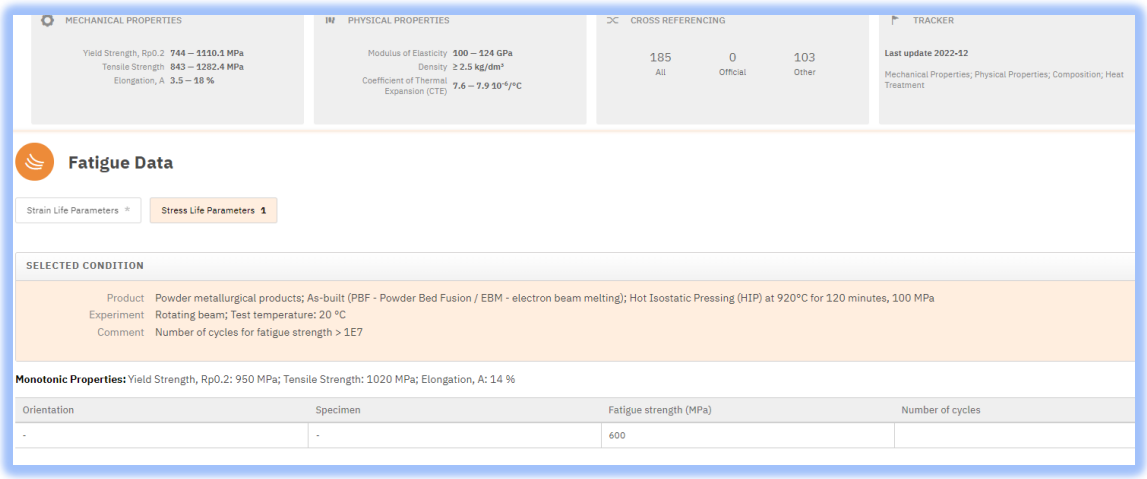

Fig.21. Fatigue data given for Ti6Al4V used in Electron Beam Melting (EBM)

Fig.22. Equivalents finder

The database permits us to find equivalents finder in function of the Brinell hardness [HB], Rockwell hardness [HR], Yield strength Rp0,2 [MPa], elongation A [%], tensile strength [MPa], reduction of area [%], Vickers hardness [HV], modulus of elasticity [GPa], density [kg/dm^3], melting temperature [°C], coefficient of thermal expansion (CTE) (10^{-6}/°C) or chemical composition, as in figure 22.

Total Materia give us the material description for the alloy Ti6Al4V used in Electron Beam Melting (EBM), specifying the applications domain, in the case of powder, is given the particles size distribution, additive laser manufacturing systems type that used this powder, the biocompatibility, as in figure 23.

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Material Description

Source	Meltio
Comment	3D printing (Additive manufacturing) - Direct Energy Deposition (DED) Machine: Meltio M450 Titanium alloy with high strength, low density, high fracture toughness, excellent corrosion resistance and superior biocompatibility
Application	Tools and prototypes, aerospace, marine, chemical
Source	Optimal Material Technology CO.,Ltd
Comment	3D printing (Additive manufacturing) - Selective Laser Melting (SLM) Machine: Concept Laser M2, EOS M 280. It has high purity, low oxygen content and good fluidity. Particle size distribution: 15-53 μm. Hall flow rate: 36 s/50g
Source	Shanghai Research Institute of Materials
Comment	3D printing (Additive manufacturing) - Selective Laser Melting (SLM), Electron Beam Melting (EBM) Particle size range: 15-45 μm. Particle size distribution d_{50}: ≤ 30 μm. Liquidity Flowability: ≤ 40s.
Source	Proto Labs, Inc.
Comment	3D printing (Additive manufacturing) - Direct Metal Laser Sintering (DMLS) Mechanical properties of Ti6Al4V are comparable to wrought titanium for tensile strength, elongation, and hardness.
Application	It is used in a variety of medical applications which require high strength.

Application	It is used in a variety of medical applications which require high strength.
Source	Digital Metal (part of Höganäs Group Company)
Comment	3D printing (Additive manufacturing) - Binder Jetting Machine: DM P2500
Source	Materialise
Comment	3D printing (Additive manufacturing) - Direct Metal Laser Sintering (DMLS) Titanium alloy that combines excellent mechanical properties with very low specific weight and corrosion resistance. Available like Standard Grade and Performance Grade.
Application	Aeronautics, functional prototypes, solid end-use parts, medical devices and spare parts
Source	Arcam AB
Comment	3D printing (Additive manufacturing) Titanium alloy with the high strength, good machinability, low weight ratio and outstanding corrosion resistance.
Application	Typically used for: direct manufacturing of parts and prototypes for racing and aerospace industry, biomechanical applications, such as implants and prosthesis, marine applications, chemical industry, gas turbines.
Source	Sintavia
Comment	3D printing (Additive manufacturing) - Direct Metal Laser Sintering (DMLS) Corrosion resistance, strength, temperature resistance and weight reduction.
Source	Sonaxys sp. z o.o.
Comment	3D printing (Additive manufacturing) - Selective Laser Melting (SLM) Titanium alloy powder.
Source	AIRBUS APWORKS GmbH
Comment	3D printing (Additive manufacturing) - Laser Powder Bed Additive Layer Manufacturing (ALM) Light weight titanium alloy powder. Excellent mechanical properties and corrosion resistance. Smallest wall thickness (mm): 1.0
Application	Aerospace, motor racing, and also for the production of biomedical implants.

Source	**Heraeus Additive Manufacturing GmbH**
Comment	3D printing (Additive manufacturing) - Laser Powder Bed Fusion (PBF-LB) High strength titanium alloy with low weight, good biocompatibility and high corrosion resistance. Particle Size Distribution (μm): 15-45 and 15-53
Application	Medical, aerospace and automotive
Source	**3T Additive Manufacturing Ltd (former 3T RPD Ltd.)**
Comment	3D printing (Additive manufacturing) - Direct Metal Laser Sintering (DMLS) Machine: EOSINT M290, EOSINT M280, EOSINT M400, EOSINT M400-4 Titanium alloy powder. Corrosion resistance, lightweight, biocompatible, weldable.
Application	Prototyping, engineering, biomedical implants, small series production
Source	**Vday Additive Manufacturing Technology Co., Ltd.**
Comment	3D printing (Additive manufacturing) - Selective Laser Melting (SLM), Electron Beam Melting (EBM) Titanium alloy powder. High strength to weight ratio, good mechanical properties, excellent corrosion resistance, good biocompatibility
Application	Medical implants, automotive, aerospace, mold, energy and power, electronics

Fig.23. Material Description - for Ti6Al4V used in Electron Beam Melting (EBM)

In the figure 24, it is presented how can discovery the material type, choosing the domain for Brinell Hardness [HB], for the temperature 0-30°C on X axis, meaning from 500 to 800, and the compression modulus [GPa], for the temperature 0-30°C, from 100-124, and are given 2 group types, ferrous alloys and nonferrous alloy. In figure 25, the database permits us to see the material properties if it is known the standard ASTM, the standard number.

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Fig.24. Material discovery

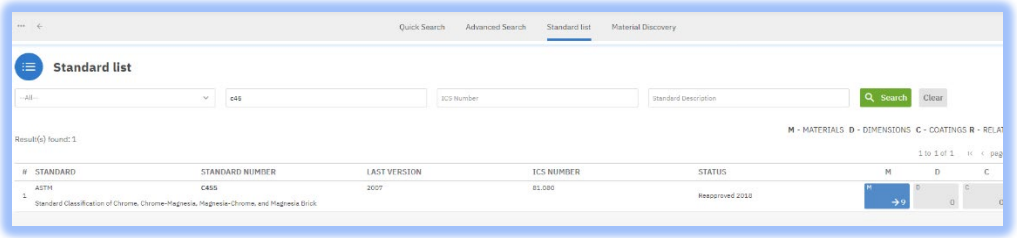

Fig.25. Standard list

3. Total Materia database – Search algorithms used for identification the unknown metallic materials

For the chemical composition Co 54,31 %, Cr 23,08 %, Mo 11,12 %, W 7,85 %, Si 3,35 % and Mn, Fe < 0,1, using the algorithms of the Total Materia database, it will identify the material with this chemical composition, as in the figures 26 and 27.

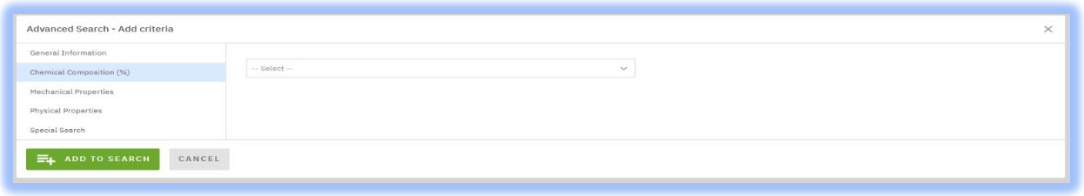

Fig.26. Algorithms used for identification the unknown materials

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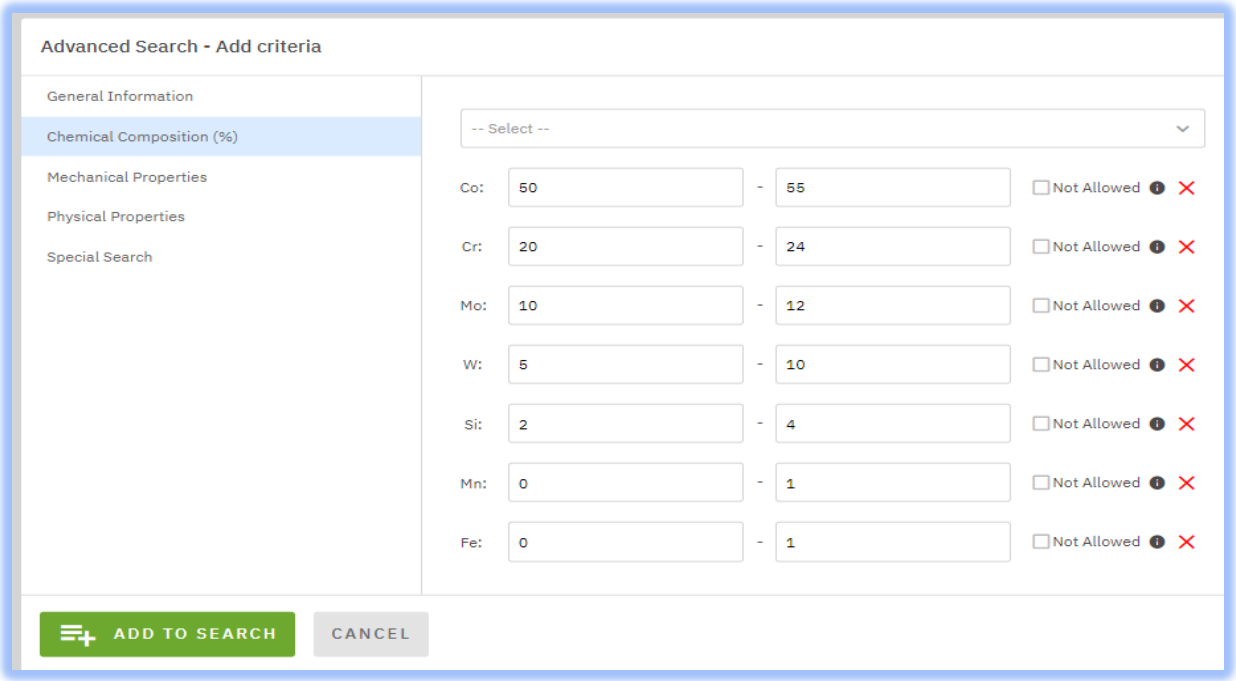

Fig.27. Chemical composition selection

When we want to change the chemical composition, it must click on clear.

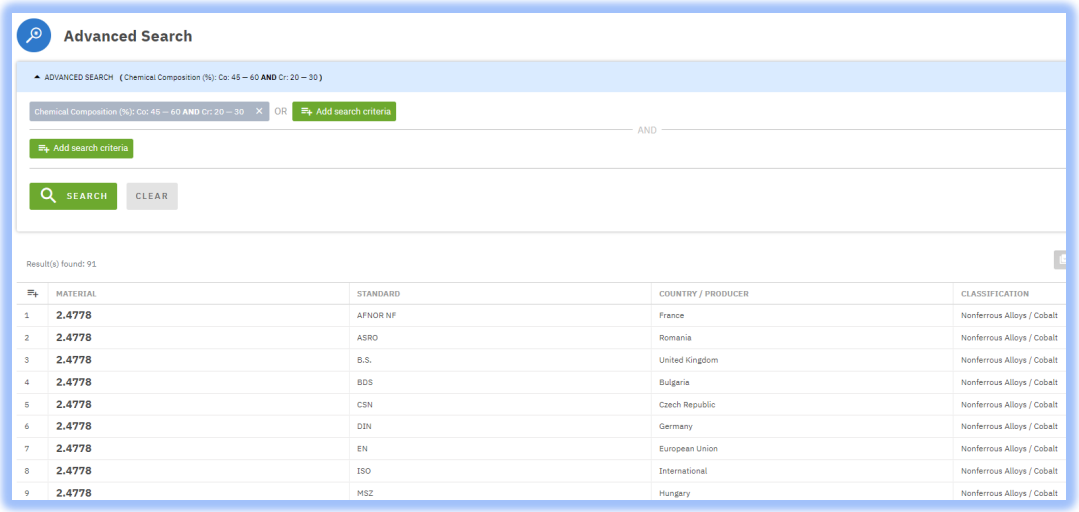

Fig.28. Co-Cr alloy results that have the respective chemical composition

In the figure 28 are presented the Co-Cr alloy results that have the respective chemical composition.

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The first is the material 2.4778, standard AFNOR NF, France and if we give click, can know the mechanical properties, the chemical composition, and its applications. In the figure 29 is presented the determination of the material: CoCr28 and their properties. The material description is presented in the figure 30.

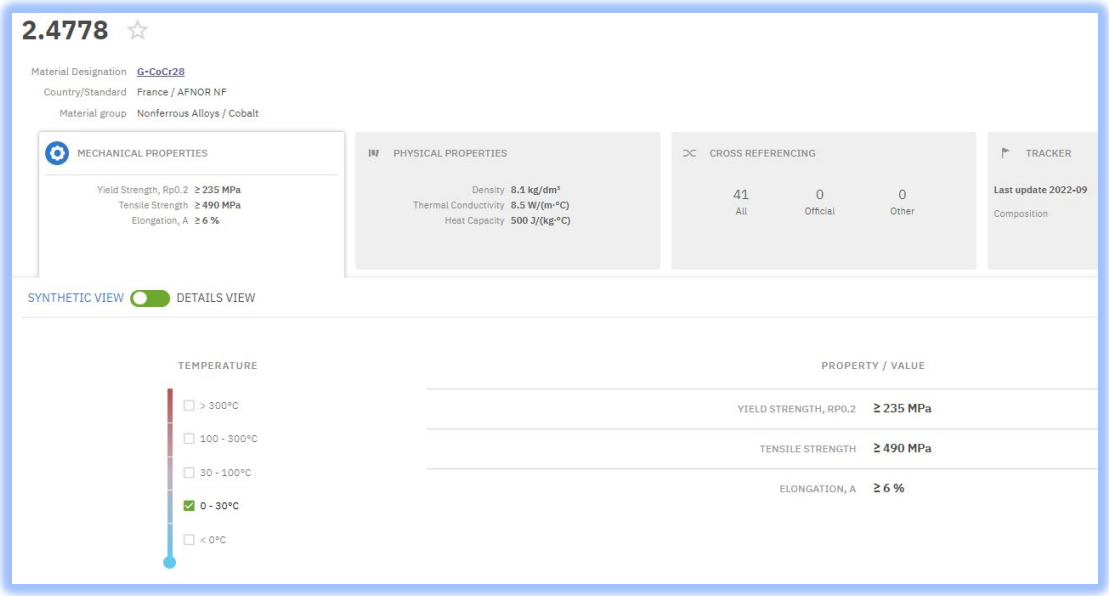

Fig.29. Determination of the material: CoCr28 and their properties

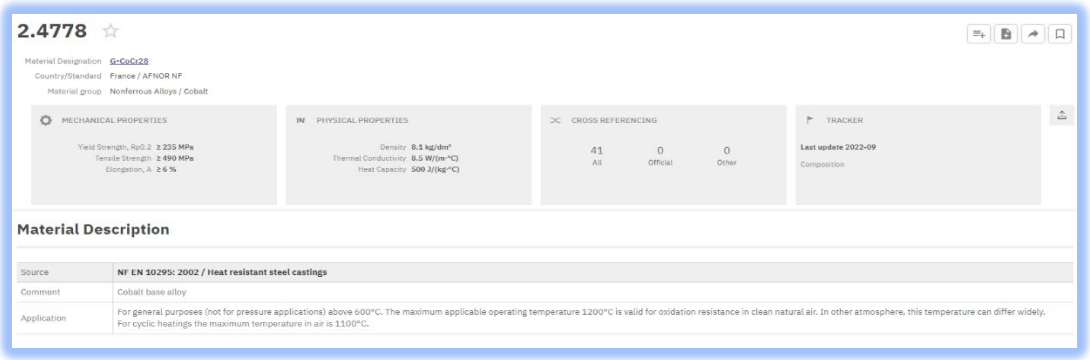

Fig.30. Material description of CoCr28

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4. Total Materia database – polymers, ceramics and composite materials

Total Materia database is used too for the polymers (Fig.31), ceramics and composite materials.

The database given 125 results of PLA types, as in the figure 32.

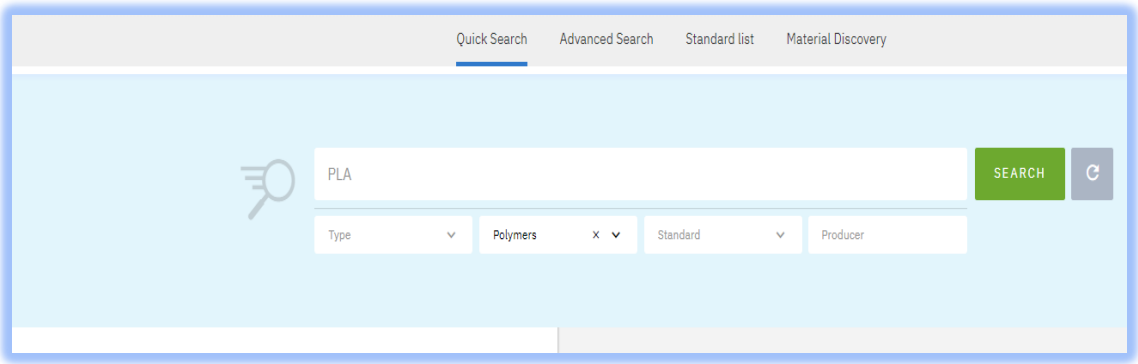
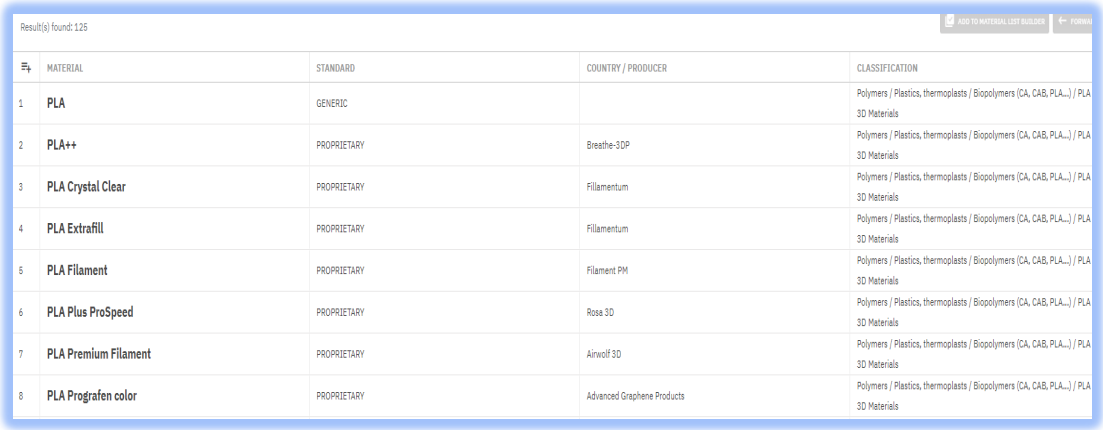


Fig.31. Total Materia database for the polymers



Result(s) found: 125

	MATERIAL	STANDARD	COUNTRY / PRODUCER	CLASSIFICATION
1	PLA	GENERIC		Polymers / Plastics, thermoplasts / Biopolymers (CA, CAB, PLA...) / PLA 3D Materials
2	PLA++	PROPRIETARY	Breathe-3DP	Polymers / Plastics, thermoplasts / Biopolymers (CA, CAB, PLA...) / PLA 3D Materials
3	PLA Crystal Clear	PROPRIETARY	Fillamentum	Polymers / Plastics, thermoplasts / Biopolymers (CA, CAB, PLA...) / PLA 3D Materials
4	PLA Extrafill	PROPRIETARY	Fillamentum	Polymers / Plastics, thermoplasts / Biopolymers (CA, CAB, PLA...) / PLA 3D Materials
5	PLA Filament	PROPRIETARY	Filament PM	Polymers / Plastics, thermoplasts / Biopolymers (CA, CAB, PLA...) / PLA 3D Materials
6	PLA Plus ProSpeed	PROPRIETARY	Rosa 3D	Polymers / Plastics, thermoplasts / Biopolymers (CA, CAB, PLA...) / PLA 3D Materials
7	PLA Premium Filament	PROPRIETARY	Airwolf 3D	Polymers / Plastics, thermoplasts / Biopolymers (CA, CAB, PLA...) / PLA 3D Materials
8	PLA Prografen color	PROPRIETARY	Advanced Graphene Products	Polymers / Plastics, thermoplasts / Biopolymers (CA, CAB, PLA...) / PLA 3D Materials

Fig.32. 125 results of PLA types existing on the database

In figure 33, are presented the mechanical properties of PLA crystal clear.

Database give us the manufacturing processes of PLA crystal clear, such as 3D Printing and temperature used in the manufacturing processes, as in figure 34.

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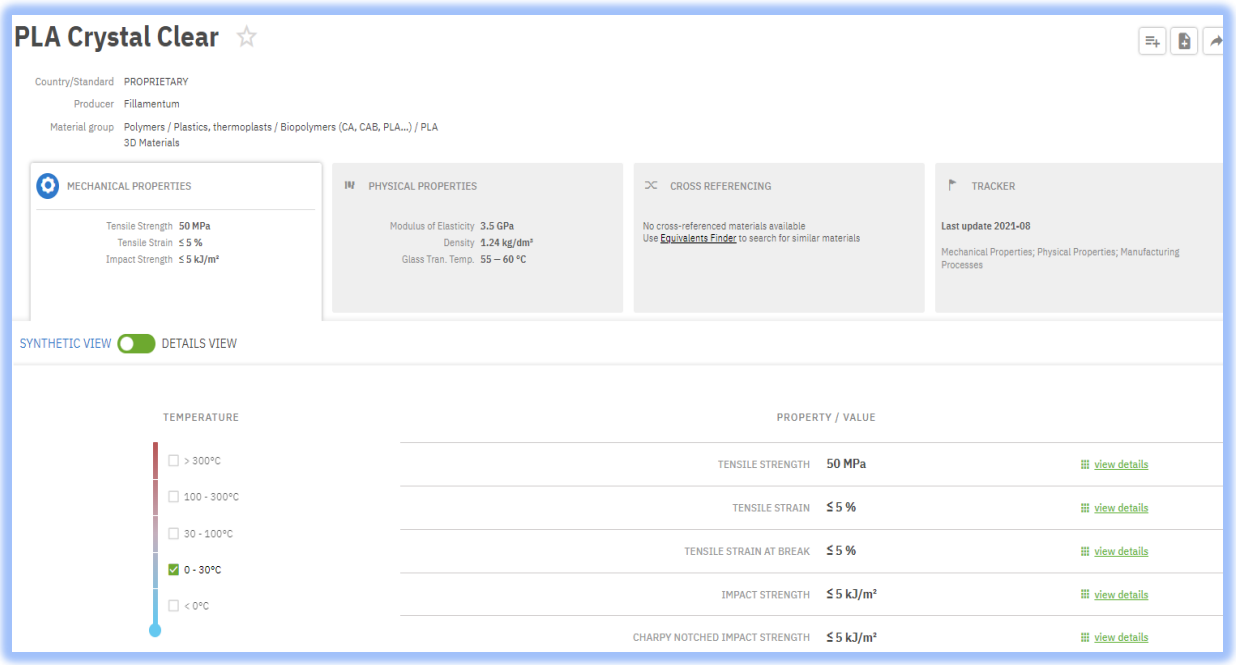
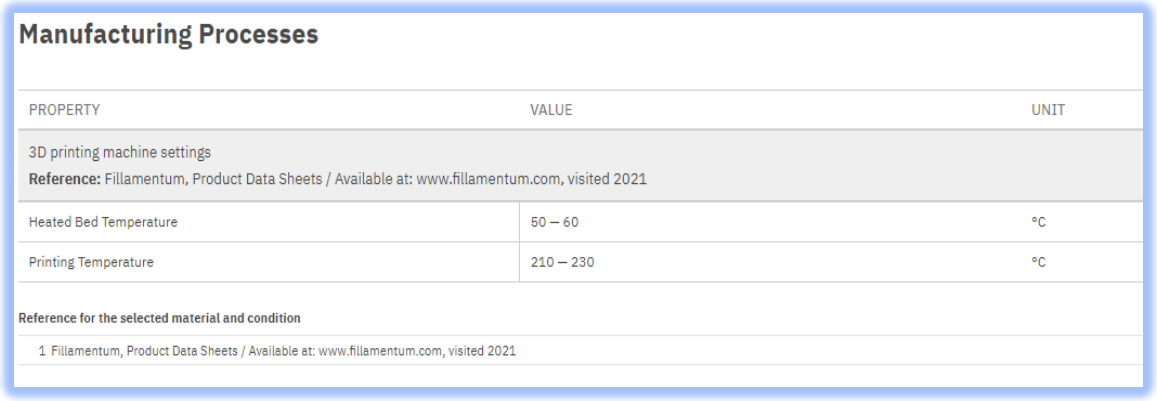


Fig.33. Mechanical properties of PLA crystal clear



Manufacturing Processes

PROPERTY	VALUE	UNIT
3D printing machine settings **Reference:** Fillamentum, Product Data Sheets / Available at: www.fillamentum.com, visited 2021		
Heated Bed Temperature	50 – 60	°C
Printing Temperature	210 – 230	°C

Reference for the selected material and condition

1 Fillamentum, Product Data Sheets / Available at: www.fillamentum.com, visited 2021

Fig.34. Manufacturing processes of PLA crystal clear

In the figure 35 is realized the material description for PLA materials, being specify that it is used in Fused Deposition Modeling (FDM) process.

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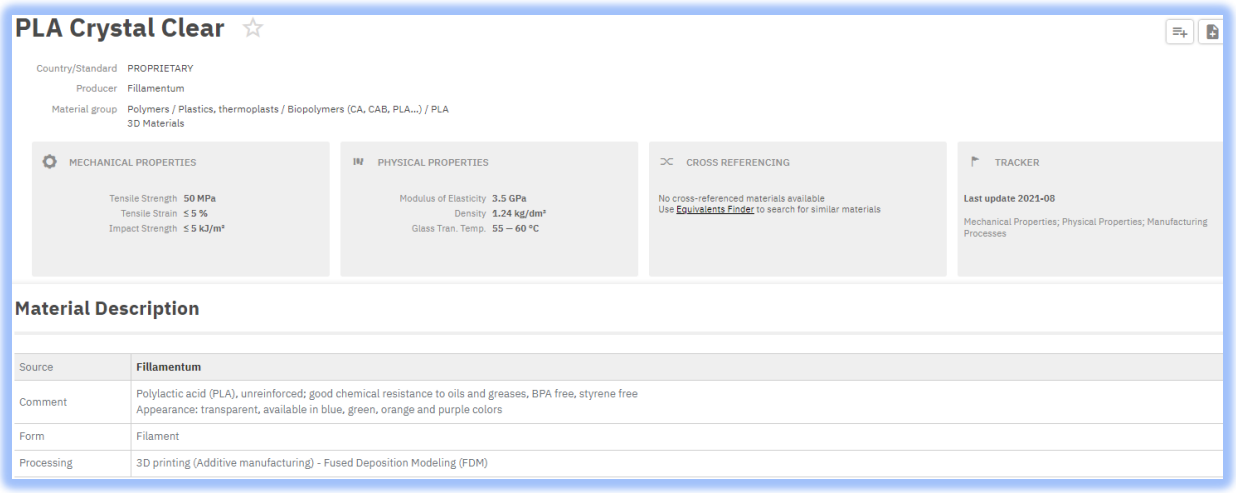

Fig.35. Material description for PLA filament

For ceramics, by example Hap, we obtain the results as in the figure 36.

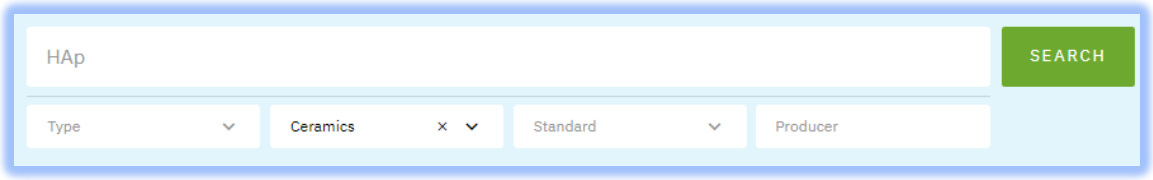

Fig.36. Ceramic search

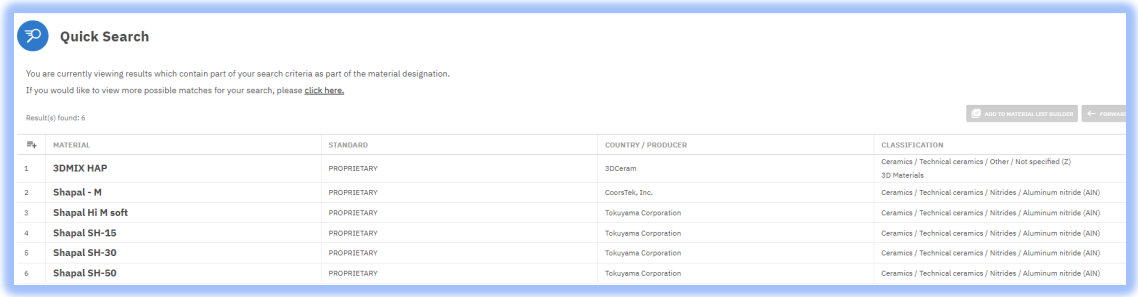

Fig.37. HAp variants existing on the database

In the figure 37, are given the Hap variants existing on the database, their producers, country and standards. In the figure 38 are given the mechanical properties of Hap.

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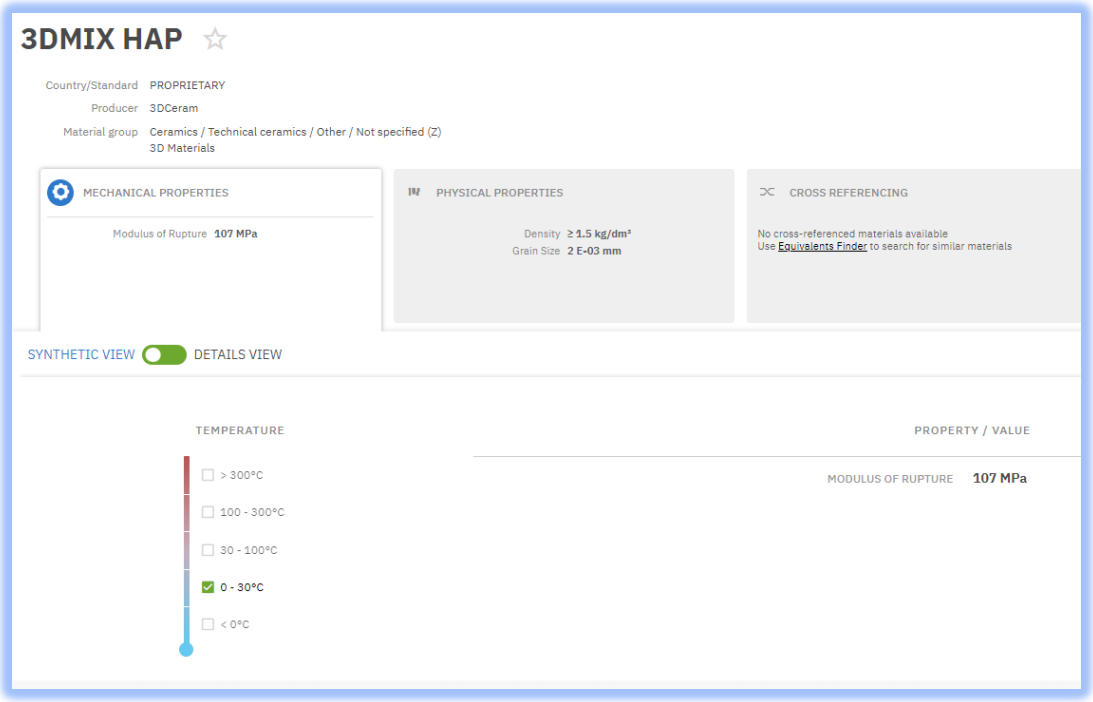

Fig.38. Mechanical properties of HAp

Material Description

Source	**3DCeram**
Comment	Hydroxyapatite (HAP), calcium phosphate; excellent bioactivity, good osseointegration Ca/P ratio = 1.65 - 1.82
Application	For tibial osteotomy wedges, intervertebral cages, cranial implants, bone substitutes, spine implants, orthopedic implants
Form	Paste
Processing	3D printing (Additive manufacturing) - Stereolithography (SLA), Sintering Machine: Ceramaker C900, Ceramaker C100

Fig.39. Material description of HAp

Hap is used in additive manufacturing in SLS and in SLA, using Ceramaker C900 or Ceramaker C100, the platform gives us inclusive information about the manufacturing systems that used this material. Hydroxyapatite is used as paste in the additive manufacturing process to obtain tibial osteotomy wedges, intervertebral cages, cranial implants, bone substitutes, spine implants or orthopaedic implants, as in the figure 39

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Concerning the composite materials, by example plywood, the database give us 3 results, such in the figures 40 and 41.

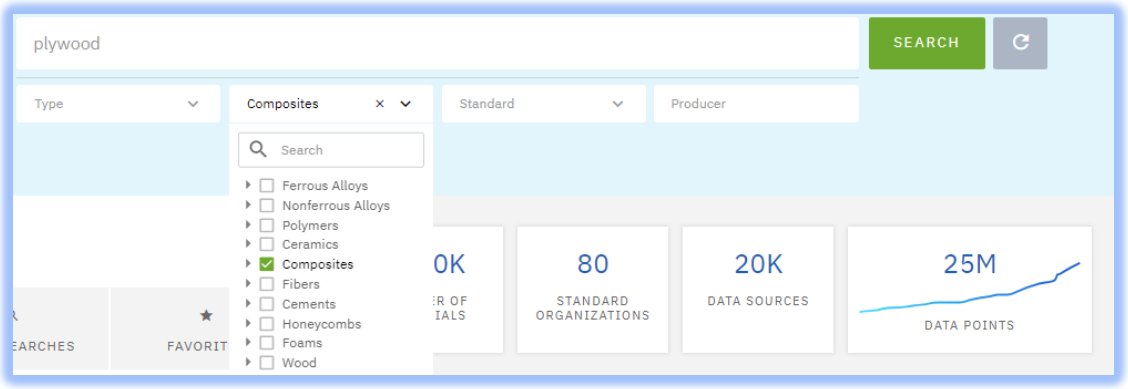

Fig.40. Quick search of plywood

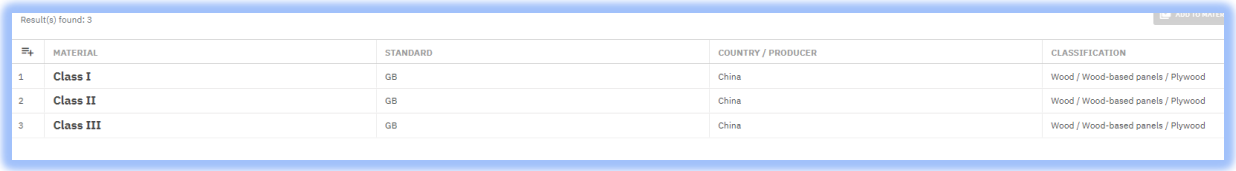

Fig.41. For composite plywood – 3 results

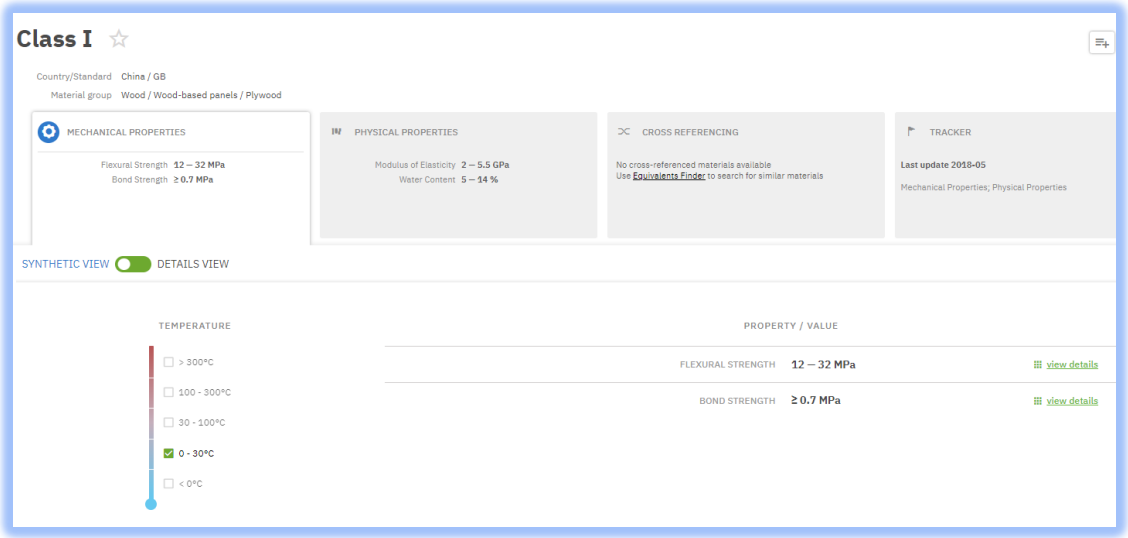

Fig.42. Mechanical properties of plywood class I

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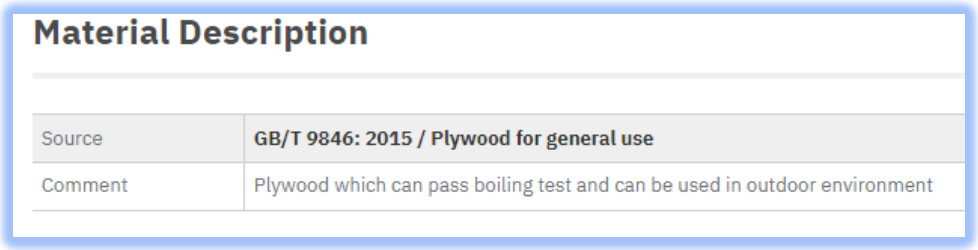
In the figure 42 are presented the mechanical properties of plywood class I. In the figure 43 is presented the material description of plywood class I, that can be used in outdoor environment.



Material Description

Source	**GB/T 9846: 2015 / Plywood for general use**
Comment	Plywood which can pass boiling test and can be used in outdoor environment

Fig.43. Material description of plywood class I

5. Conclusions

In the last years, the materials developed very much, appeared different news materials with very interesting properties realized by different world companies, that can be used in Additive Manufacturing and in other manufacturing domain to realize medical parts or for industrial domain and grace to this database, all materials developed are introduced in this platform, giving us the possibility to choose, the chemical composition, the mechanical properties, or using the search algorithms, finding the unknown material, in function of the chemical or mechanical properties.
The implications of the present research would be interesting for the manufacture by Additive Manufacturing different medical parts, using different materials using the database Total Materia, or others to know the mechanical and chemical properties that are very important to establish the manufacturing parameters and manufacturing systems and tools.

References

1. Ratner Buddy D., Hoffman Allan S., Schoen Frederick J., Lemons Jack E.- Biomaterials Science, An introduction to materials in medicine –Academic Press, 2013;
2. Materia Total database - https://portal.totalmateria.com/en/search/advanced
3. https://link.springer.com/chapter/10.1007/978-3-662-46836-4_7

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