CASI STUDIO

Paletta di turbina

Paletta di Turbina

This case study demonstrates how CES EduPack can help to suggest alternative materials for turbo blades, which relates to typical aerospace or automotive applications. We show how to ensure that requirements on material properties, such as $\boxed{\text{high temperature}}$ and $\boxed{\text{resistance to fast fracture and centrifugal loading}}$ are met. The case is inspired by an industrial R&D project presented at a conference.

Materiali delle palette di turbina

A turbocharger works in a very hostile environment. Exhaust gases that drive the turbine **can exceed 1000°C** and are very corrosive.

The turbine disc, is located in a high-velocity jet of those gases.

There is some expansion of the gas across the turbine nozzle which reduces the temperature but, at the tips of the turbine rotor, it can approach exhaust gas temperatures. The turbine blades of jet engines work in similar or worse conditions from around 800°C upwards.

Moreover, the rotor system on many turbochargers operate in excess of **100000 RPM**. **Very high tensile** loads result from the centrifugal forces, in addition to vibrational and bending loads. **Thermal shock and Creep are also issues.**

Nickel-based superalloys are therefore used for such turbine discs. These alloys retain high strength values even at high temperatures.

- Typical turbines are investment-cast from Inconel 713 C or 713 LC and turbine wheel castings can be treated with Hot Isostatic Processing (HIP) for improved structure, then heat-treated for the required strength. In this case study, we look for alternative material candidates to Inconel 713 for turbine blades in automotive or aerospace applications.

Requisiti

A turbine blade is subjected to huge centrifugal load. The blades also must not fail due to bending during sudden turbine acceleration or vibrations, and consequently requires high strength and resistance to brittle failure.

It is well known that some superalloys and technical ceramics have sufficient properties to resist high temperatures, corrosion and creep.

In this case, we can focus on resistance to **fast fracture**, which would result in catastrophic failure with blades becoming projectiles, as well as resistance to **centrifugal loading**.

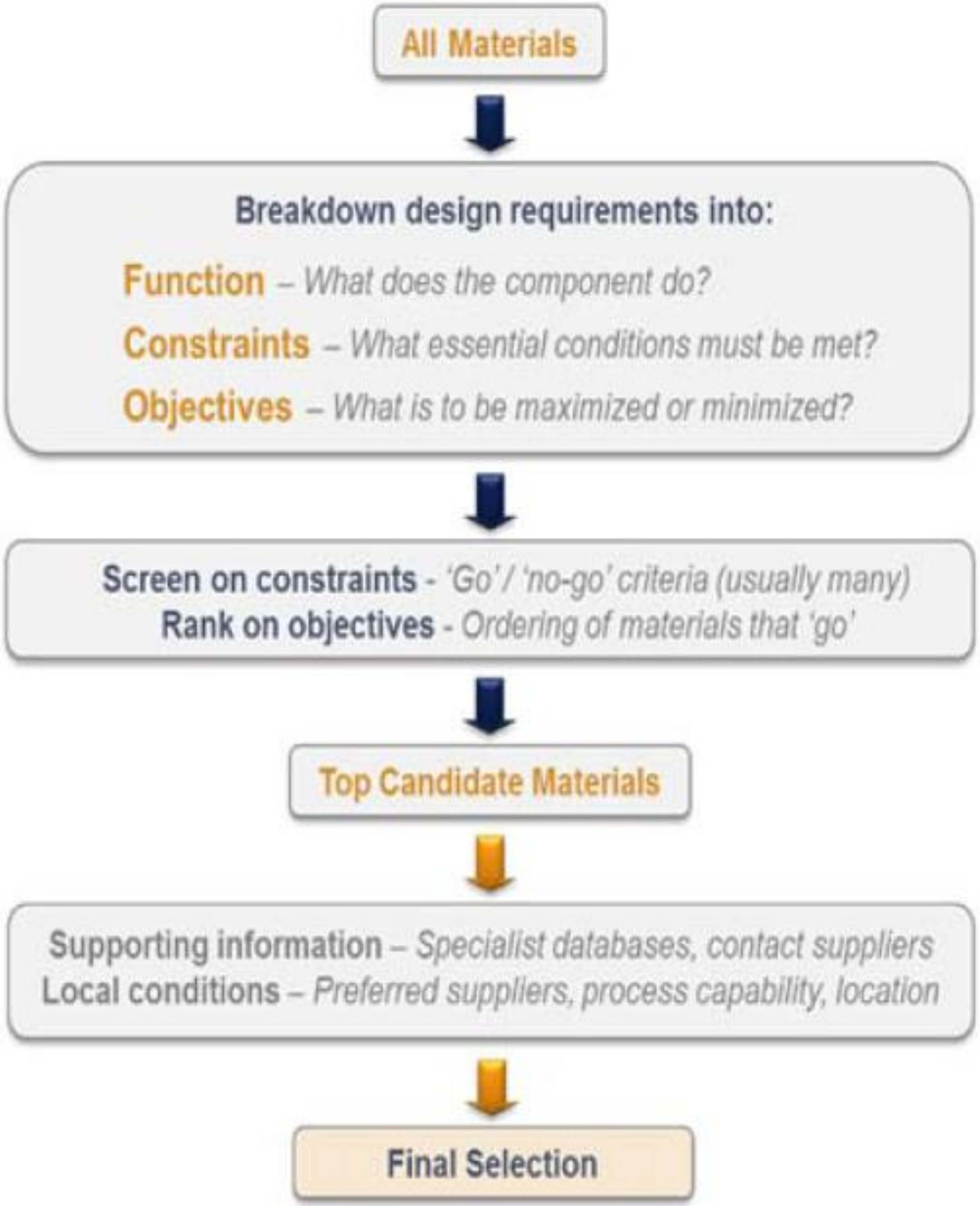
The fracture will be governed by crack propagation properties (***Fracture toughness***). For the centrifugal forces, we look for high strength in combination with low density for this particular application. **Tensile strength, Yield strength** or **Fatigue strength** are possible mechanical properties to consider.

Fatigue strength can be used for cyclic loads.

A more thorough case study of material properties for jet turbine blades using the same database and selection methodology has been published by **NASA**.

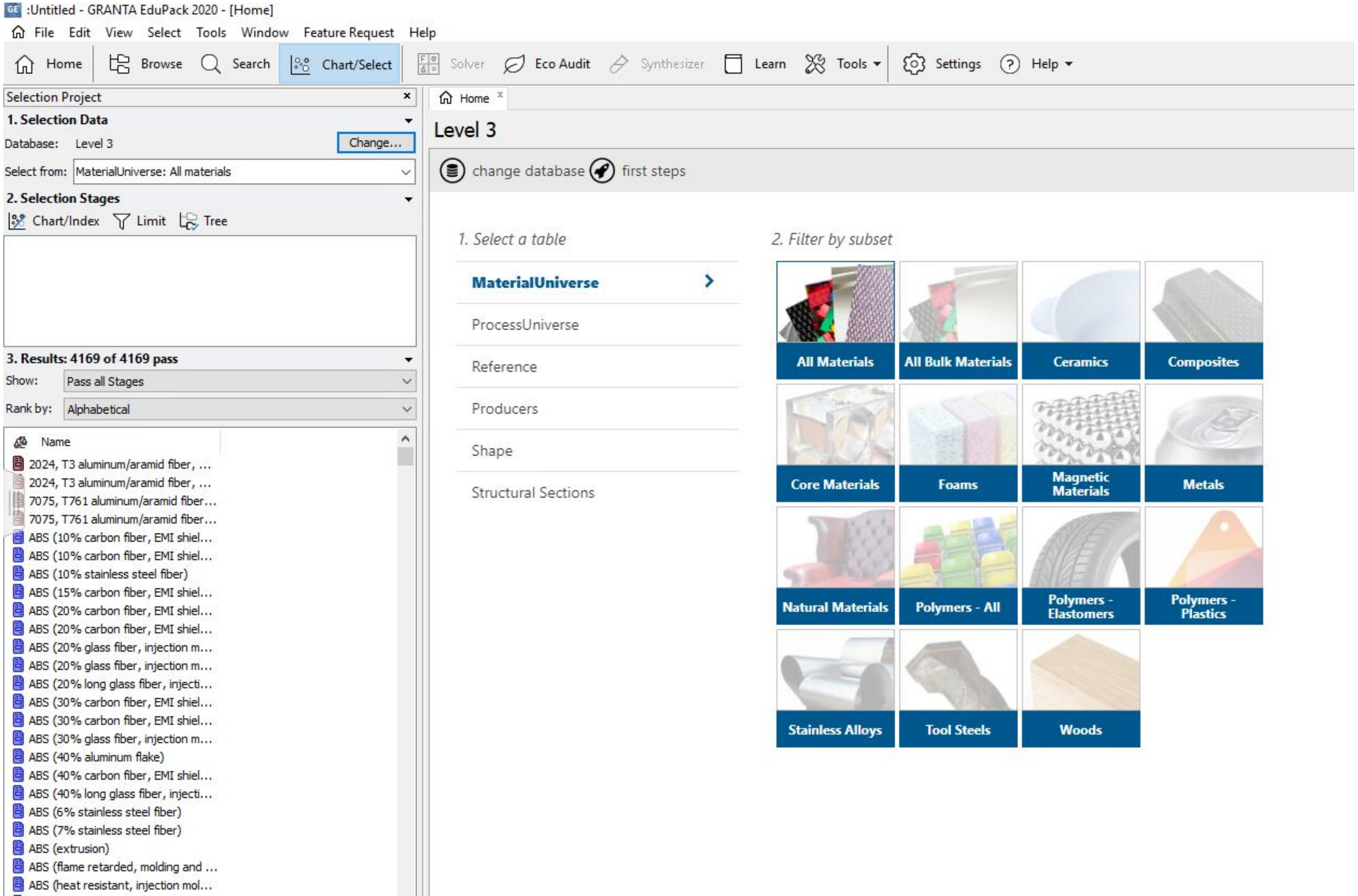
In the NASA study, blade bending loads and vibrations were considered as well as centrifugal load.

Temperature ranges (900-1000 °C) without taking into account internal cooling, thermal barrier coatings or single crystal designs.


All Materials
Breakdown design requirements into:
Function – What does the component do?
Constraints – What essential conditions must be met?
Objectives – What is to be maximized or minimized?
Screen on constraints - 'Go' / 'no-go' criteria (usually many)
Rank on objectives - Ordering of materials that 'go'
Top Candidate Materials
Supporting information – Specialist databases, contact suppliers
Local conditions – Preferred suppliers, process capability, location
Final Selection

Vincoli e limiti

- Adequate Fatigue Strength (at 10^7 cycles) *>360 MPa*
- Thermally stable at Service temperatures > *900°C*
- Resistant to oxidation at high temperatures: *Excellent*
- Only *Technical ceramics* and *Metal alloys* considered
- Metals should be manufactured by *Investment casting*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File Edit View Select Tools Window Feature Request Help
Home Browse Search Chart/Select Solver Eco Audit Synthesizer Learn Tools Settings Help
Selection Project
1. Selection Data
Database: Level 3
Change...
Select from: MaterialUniverse: All materials
2. Selection Stages
Chart/Index Limit Tree
3. Results: 4169 of 4169 pass
Show: Pass all Stages
Rank by: Alphabetical
Name
2024, T3 aluminum/aramid fiber, ...
2024, T3 aluminum/aramid fiber, ...
7075, T761 aluminum/aramid fiber...
7075, T761 aluminum/aramid fiber...
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ABS (10% carbon fiber, EMI shiel...
ABS (10% stainless steel fiber)
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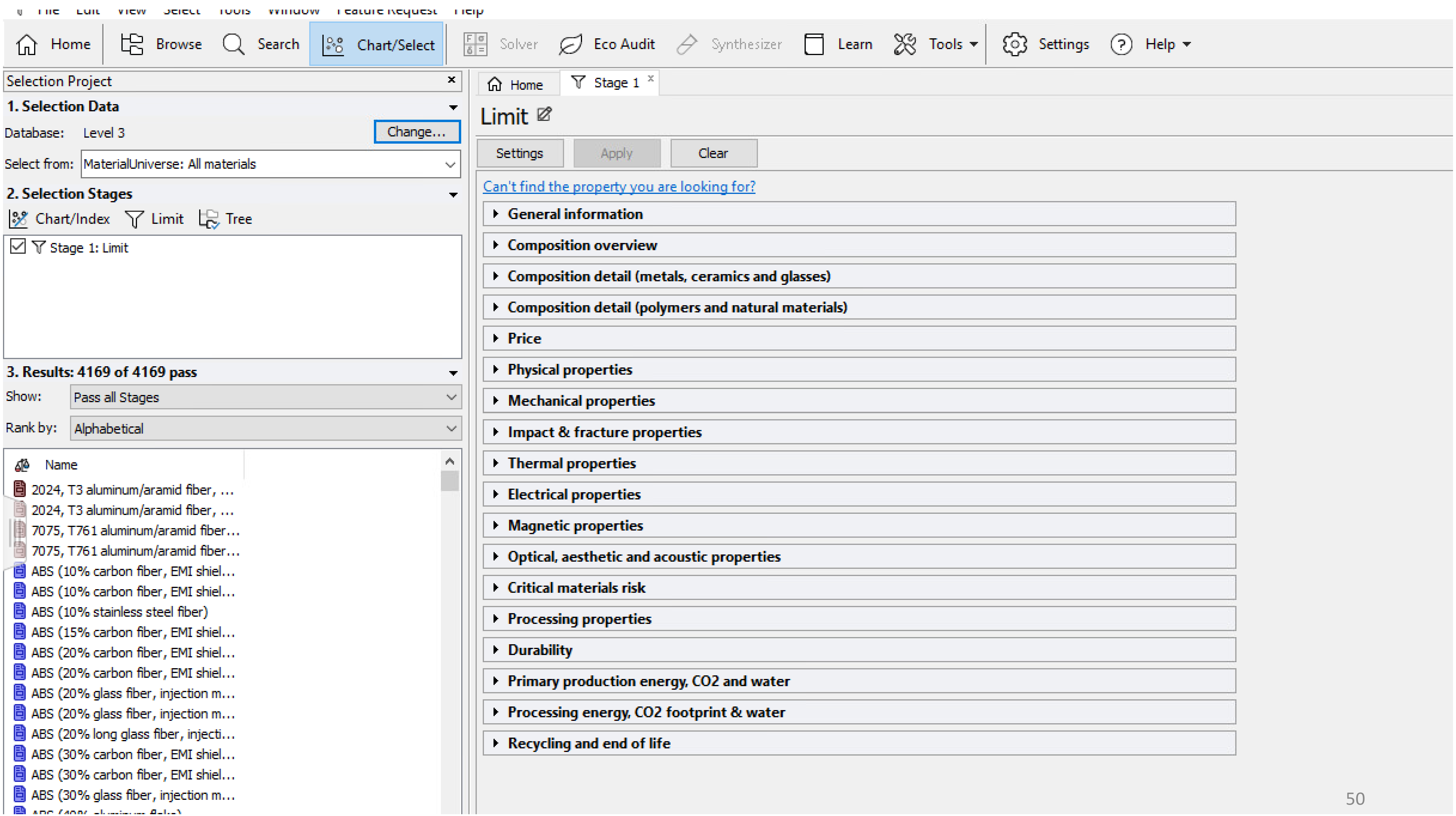
ABS (40% long glass fiber, injecti...
ABS (6% stainless steel fiber)
ABS (7% stainless steel fiber)
ABS (extrusion)
ABS (flame retarded, molding and ...
ABS (heat resistant, injection mol...
Home
Level 3
change database
first steps
1. Select a table
MaterialUniverse
ProcessUniverse
Reference
Producers
Shape
Structural Sections
2. Filter by subset
All Materials
All Bulk Materials
Ceramics
Composites
Core Materials
Foams
Magnetic Materials
Metals
Natural Materials
Polymers - All
Polymers - Elastomers
Polymers - Plastics
Stainless Alloys
Tool Steels
Woods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Stage 1: Limit
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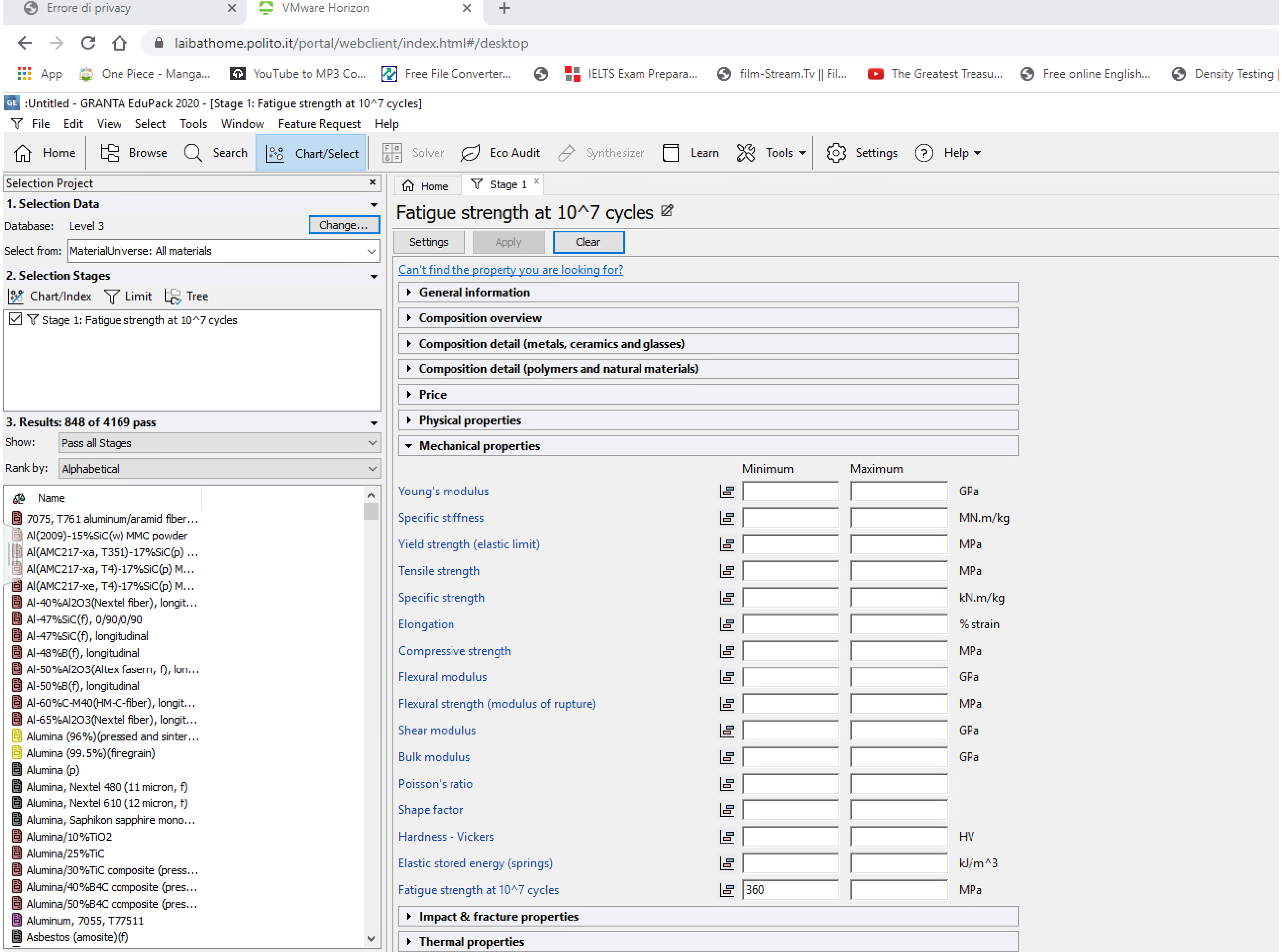
ABS (20% carbon fiber, EMI shiel...
ABS (20% glass fiber, injection m...
ABS (20% glass fiber, injection m...
ABS (20% long glass fiber, injecti...
ABS (30% carbon fiber, EMI shiel...
ABS (30% carbon fiber, EMI shiel...
ABS (30% glass fiber, injection m...
Home
Stage 1
Limit
Settings
Apply
Clear
Can't find the property you are looking for?
General information
Composition overview
Composition detail (metals, ceramics and glasses)
Composition detail (polymers and natural materials)
Price
Physical properties
Mechanical properties
Impact & fracture properties
Thermal properties
Electrical properties
Magnetic properties
Optical, aesthetic and acoustic properties
Critical materials risk
Processing properties
Durability
Primary production energy, CO2 and water
Processing energy, CO2 footprint & water
Recycling and end of life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1. Selection Data
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Change...
Select from: MaterialUniverse: All materials
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Limit
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Stage 1: Fatigue strength at 10^7 cycles
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Show: Pass all Stages
Rank by: Alphabetical
Name
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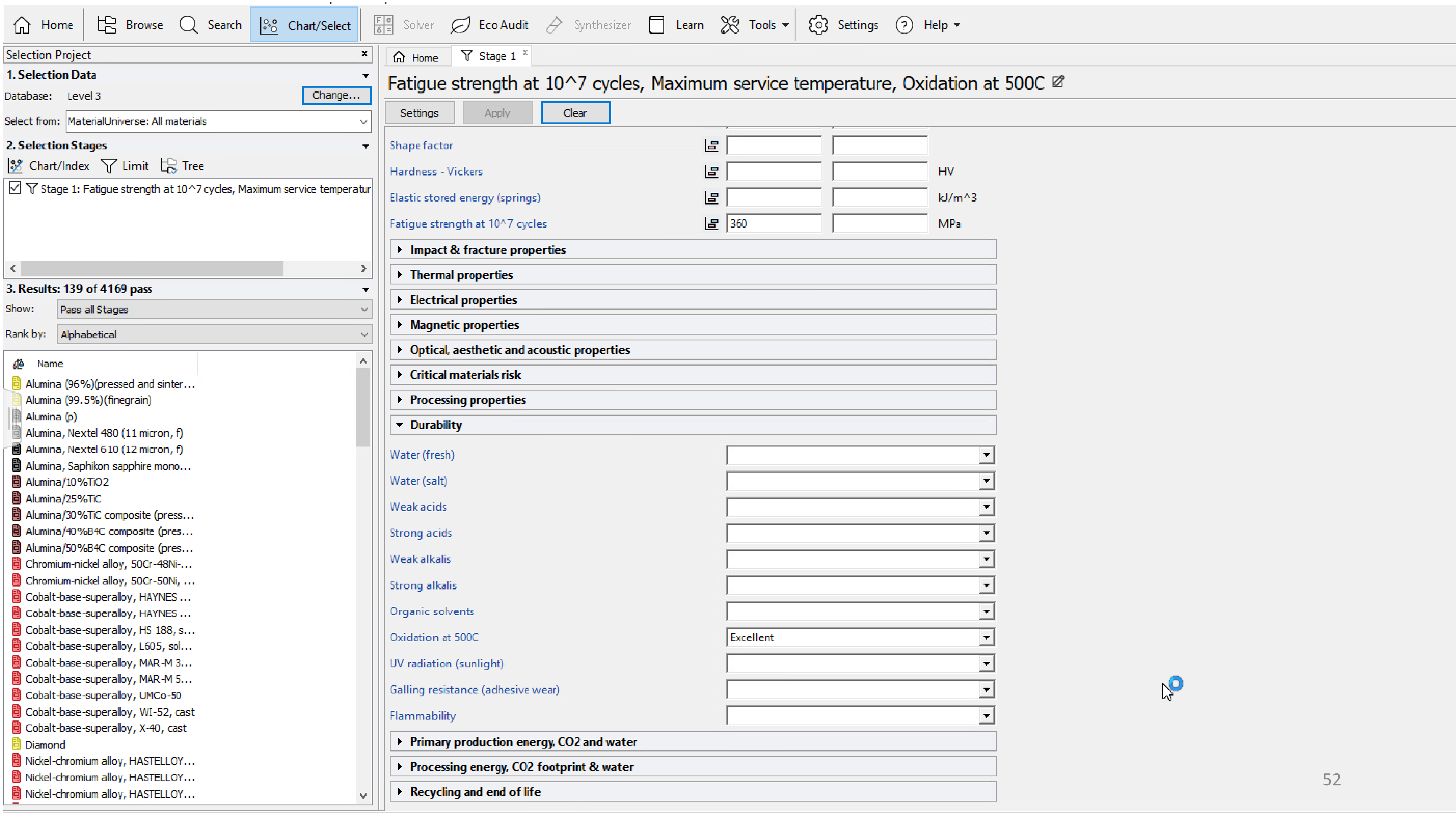
Al(2009)-15%SiC(w) MMC powder
Al(AMC217-xa, T351)-17%SiC(p) ...
Al(AMC217-xa, T4)-17%SiC(p) M...
Al(AMC217-xe, T4)-17%SiC(p) M...
Al-40%Al2O3(Nextel fiber), longit...
Al-47%SiC(f), 0/90/0/90
Al-47%SiC(f), longitudinal
Al-48%B(f), longitudinal
Al-50%Al2O3(Altex fasern, f), lon...
Al-50%B(f), longitudinal
Al-60%C-M40(HM-C-fiber), longit...
Al-65%Al2O3(Nextel fiber), longit...
Alumina (96%)(pressed and sinter...
Alumina (99.5%)(finegrain)
Alumina (p)
Alumina, Nextel 480 (11 micron, f)
Alumina, Nextel 610 (12 micron, f)
Alumina, Saphikon sapphire mono...
Alumina/10%TiO2
Alumina/25%TiC
Alumina/30%TiC composite (press...
Alumina/40%B4C composite (pres...
Alumina/50%B4C composite (pres...
Aluminum, 7055, T77511
Asbestos (amosite)(f)
Home
Stage 1
Fatigue strength at 10^7 cycles
Settings
Apply
Clear
Can't find the property you are looking for?
General information
Composition overview
Composition detail (metals, ceramics and glasses)
Composition detail (polymers and natural materials)
Price
Physical properties
Mechanical properties
Minimum
Maximum
Young's modulus GPa
Specific stiffness MN.m/kg
Yield strength (elastic limit) MPa
Tensile strength MPa
Specific strength kN.m/kg
Elongation % strain
Compressive strength MPa
Flexural modulus GPa
Flexural strength (modulus of rupture) MPa
Shear modulus GPa
Bulk modulus GPa
Poisson's ratio
Shape factor
Hardness - Vickers HV
Elastic stored energy (springs) kJ/m^3
Fatigue strength at 10^7 cycles 360 MPa
Impact & fracture properties
Thermal properties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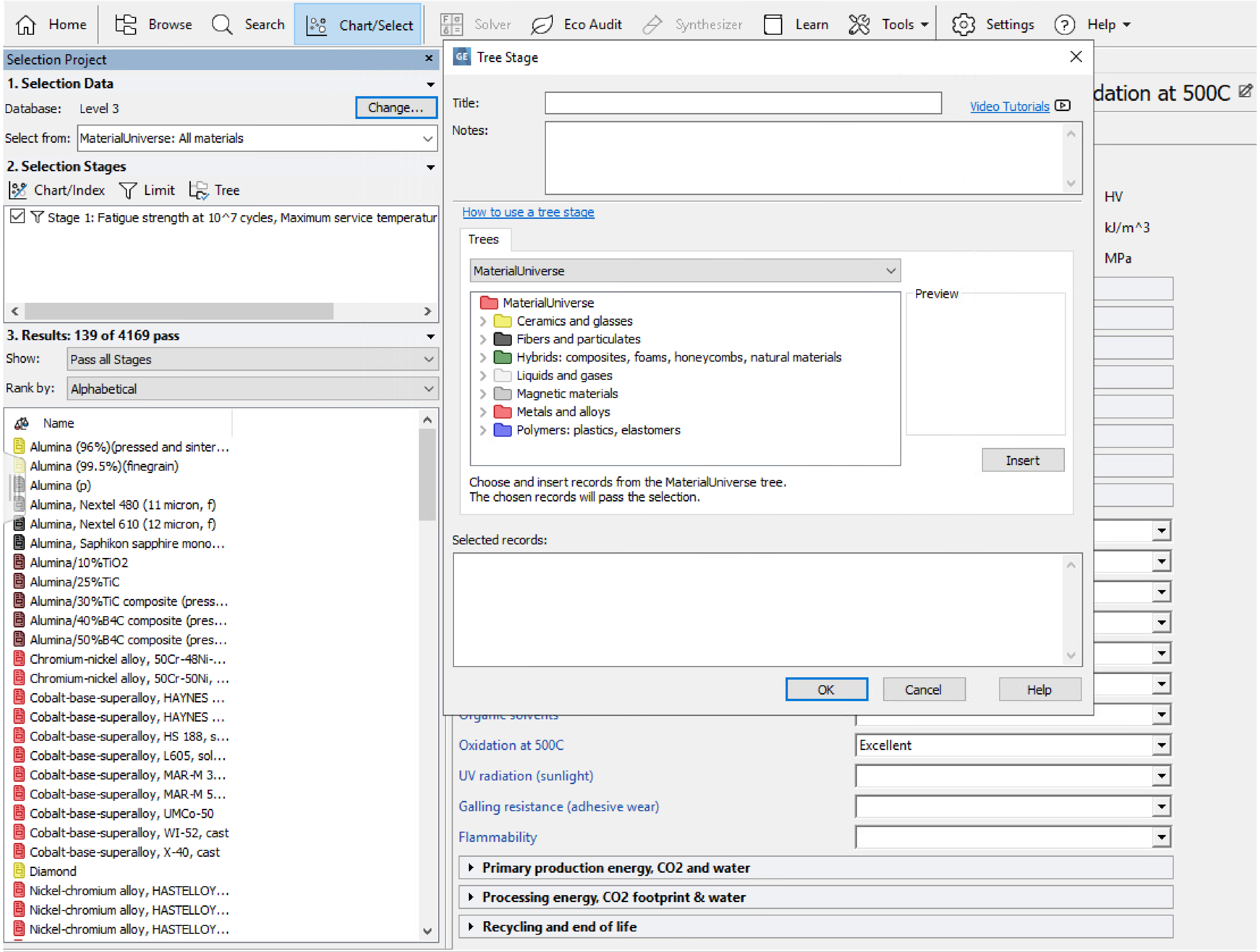
Tree
Stage 1: Fatigue strength at 10^7 cycles, Maximum service temperatur
3. Results: 139 of 4169 pass
Show: Pass all Stages
Rank by: Alphabetical
Name
Alumina (96%)(pressed and sinter...
Alumina (99.5%)(finegrain)
Alumina (p)
Alumina, Nextel 480 (11 micron, f)
Alumina, Nextel 610 (12 micron, f)
Alumina, Saphikon sapphire mono...
Alumina/10%TiO2
Alumina/25%TiC
Alumina/30%TiC composite (press...
Alumina/40%B4C composite (pres...
Alumina/50%B4C composite (pres...
Chromium-nickel alloy, 50Cr-48Ni-...
Chromium-nickel alloy, 50Cr-50Ni, ...
Cobalt-base-superalloy, HAYNES ...
Cobalt-base-superalloy, HAYNES ...
Cobalt-base-superalloy, HS 188, s...
Cobalt-base-superalloy, L605, sol...
Cobalt-base-superalloy, MAR-M 3...
Cobalt-base-superalloy, MAR-M 5...
Cobalt-base-superalloy, UMCo-50
Cobalt-base-superalloy, WI-52, cast
Cobalt-base-superalloy, X-40, cast
Diamond
Nickel-chromium alloy, HASTELLOY...
Nickel-chromium alloy, HASTELLOY...
Nickel-chromium alloy, HASTELLOY...
Home
Stage 1
Fatigue strength at 10^7 cycles, Maximum service temperature, Oxidation at 500C
Settings
Apply
Clear
Shape factor
Hardness - Vickers
HV
Elastic stored energy (springs)
kJ/m^3
Fatigue strength at 10^7 cycles
360
MPa
Impact & fracture properties
Thermal properties
Electrical properties
Magnetic properties
Optical, aesthetic and acoustic properties
Critical materials risk
Processing properties
Durability
Water (fresh)
Water (salt)
Weak acids
Strong acids
Weak alkalis
Strong alkalis
Organic solvents
Oxidation at 500C
Excellent
UV radiation (sunlight)
Galling resistance (adhesive wear)
Flammability
Primary production energy, CO2 and water
Processing energy, CO2 footprint & water
Recycling and end of life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Cobalt-base-superalloy, MAR-M 3...
Cobalt-base-superalloy, MAR-M 5...
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Cobalt-base-superalloy, WI-52, cast
Cobalt-base-superalloy, X-40, cast
Diamond
Nickel-chromium alloy, HASTELLOY...
Nickel-chromium alloy, HASTELLOY...
Nickel-chromium alloy, HASTELLOY...
Tree Stage
Title:
Video Tutorials
Notes:
How to use a tree stage
Trees
MaterialUniverse
MaterialUniverse
Ceramics and glasses
Fibers and particulates
Hybrids: composites, foams, honeycombs, natural materials
Liquids and gases
Magnetic materials
Metals and alloys
Polymers: plastics, elastomers
Preview
Insert
Choose and insert records from the MaterialUniverse tree.
The chosen records will pass the selection.
Selected records:
OK
Cancel
Help
dation at 500C
HV
kJ/m^3
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Excellent
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Galling resistance (adhesive wear)
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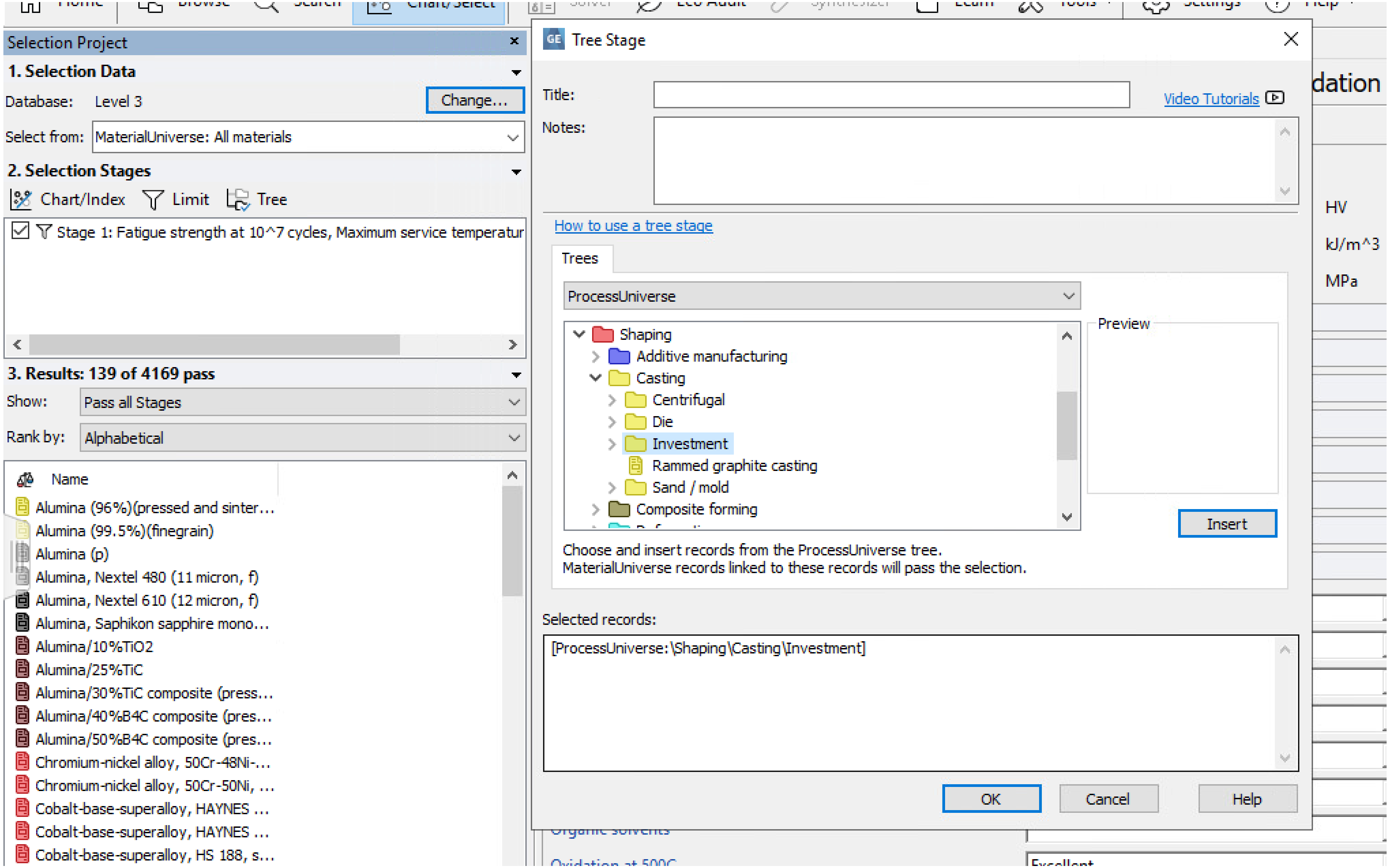
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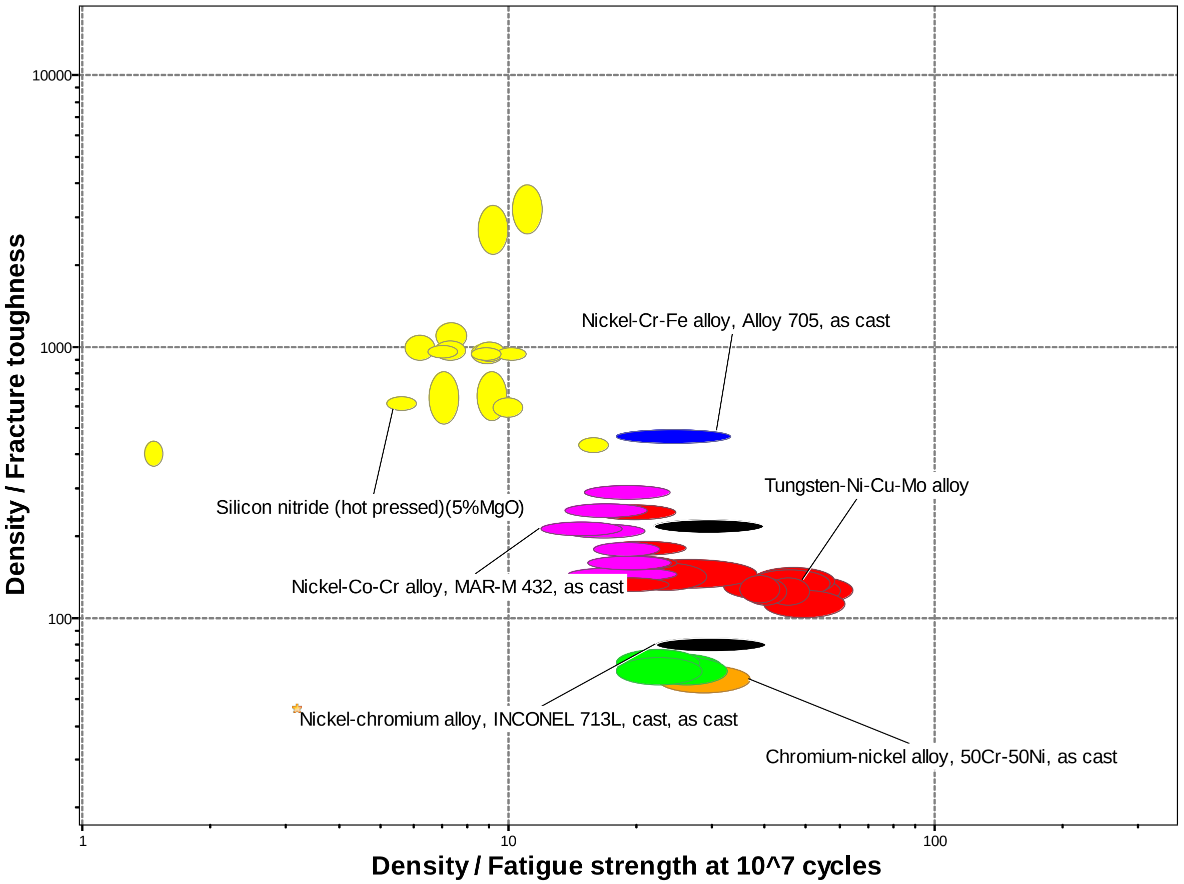
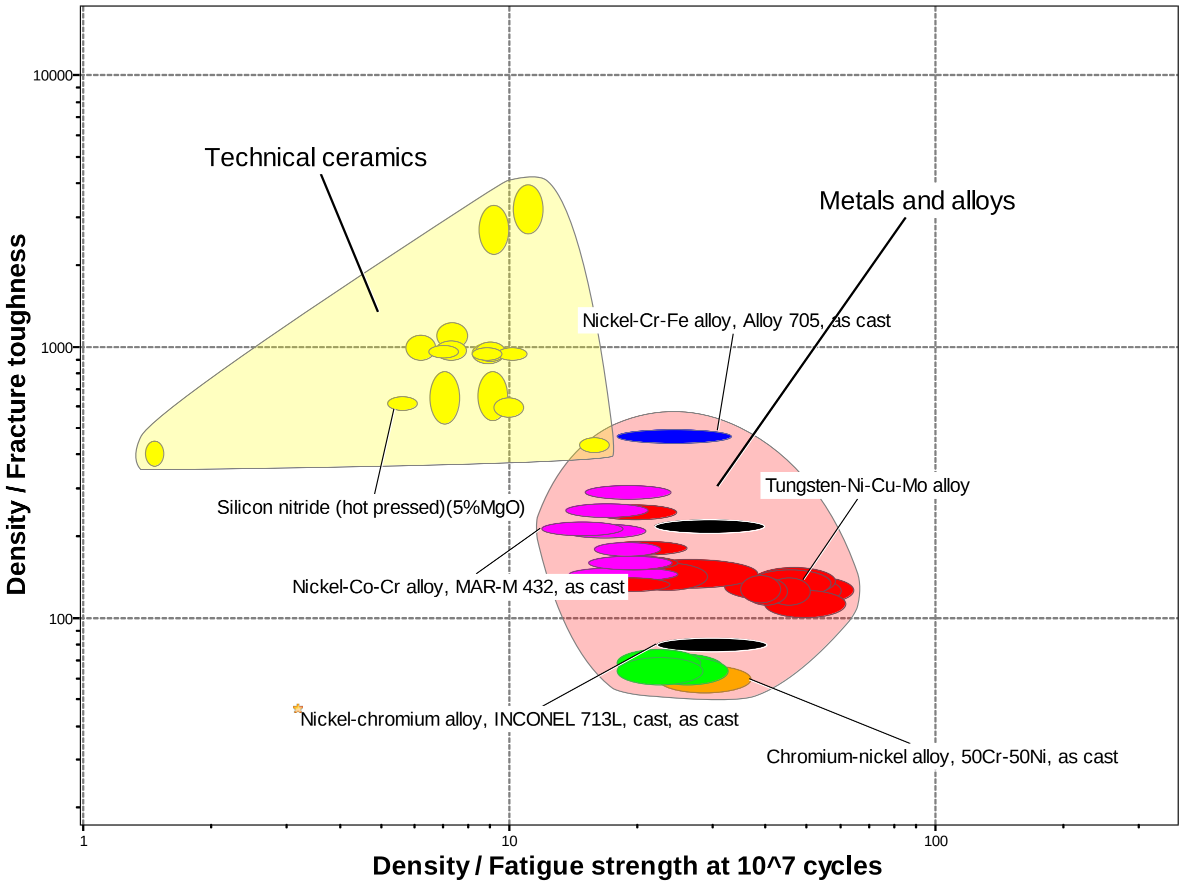
Cobalt-base-superalloy, HAYNES ...
Cobalt-base-superalloy, HAYNES ...
Cobalt-base-superalloy, HS 188, s...
Tree Stage
Title:
Notes:
Video Tutorials
How to use a tree stage
Trees
ProcessUniverse
Shaping
Additive manufacturing
Casting
Centrifugal
Die
Investment
Rammed graphite casting
Sand / mold
Composite forming
Preview
Insert
Choose and insert records from the ProcessUniverse tree.
MaterialUniverse records linked to these records will pass the selection.
Selected records:
[ProcessUniverse:\Shaping\Casting\Investment]
OK
Cancel
Help
dation
HV
kJ/m^3
MPa

Candidates at 900 °C





Tutorials and Case Studies > Materials Case Studies > Mechanical > Materials for Cooling Fans

The Model

A blade (Figure 7.1) has mean section area A and length αR, where α is the fraction of the fan radius ρ which is blade (the rest is hub). Its volume is αRA and the angular acceleration is $\omega^2 R$, so the centrifugal force at the blade root is

$$F = \rho(\alpha R A)\omega^2 R \qquad \text{(M7.1)}$$

The force is carried by the section A, so the stress at the root of the blade is

$$\sigma = \frac{F}{A} = \alpha \rho \omega^2 R^2 \qquad \text{(M7.2)}$$

This stress must not exceed the failure stress σ_f divided by a safety factor (typically about 3) which does not affect the analysis and can be ignored. The stress at which fast fracture will occur is:

$$\sigma_f = \frac{K_{1C}}{\sqrt{\pi a}},$$

where K_{1C} is the fracture toughness of the material of the blade and α is the length of the largest defect it contains. Non-destructive testing can ensure that this is less than some detection limit, a*. Thus, for safety:

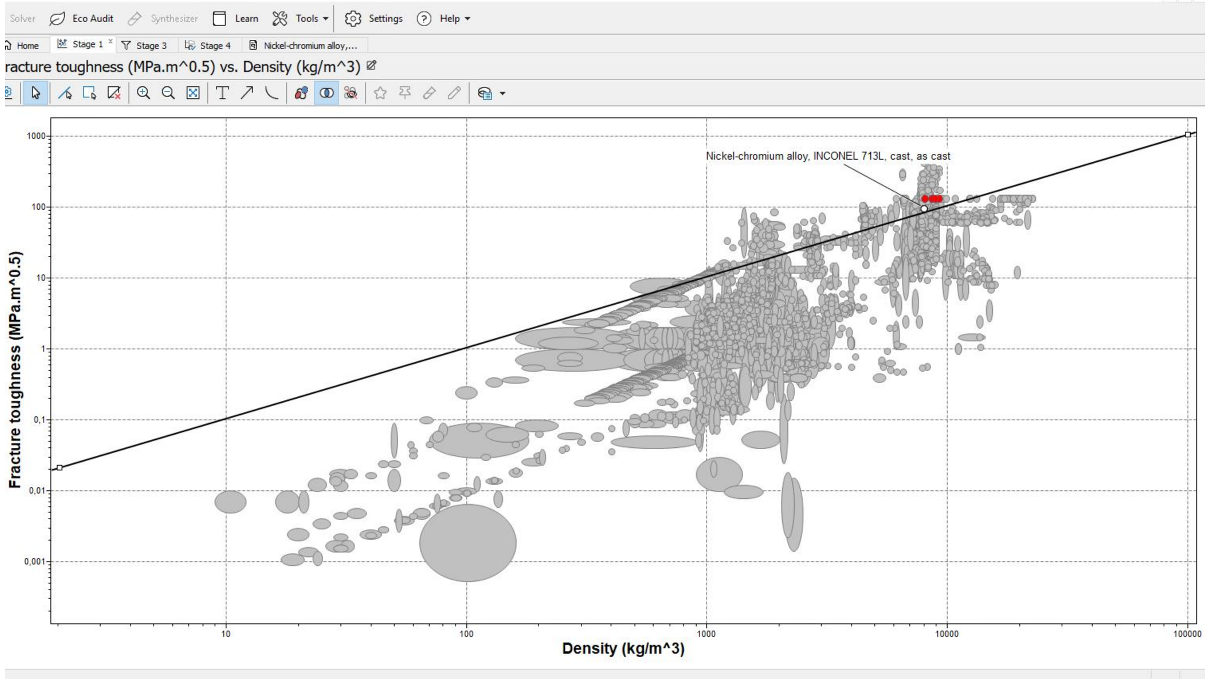
$$\alpha \rho \omega^2 R^2 < \frac{K_{1C}}{\sqrt{\pi a^*}},$$

or

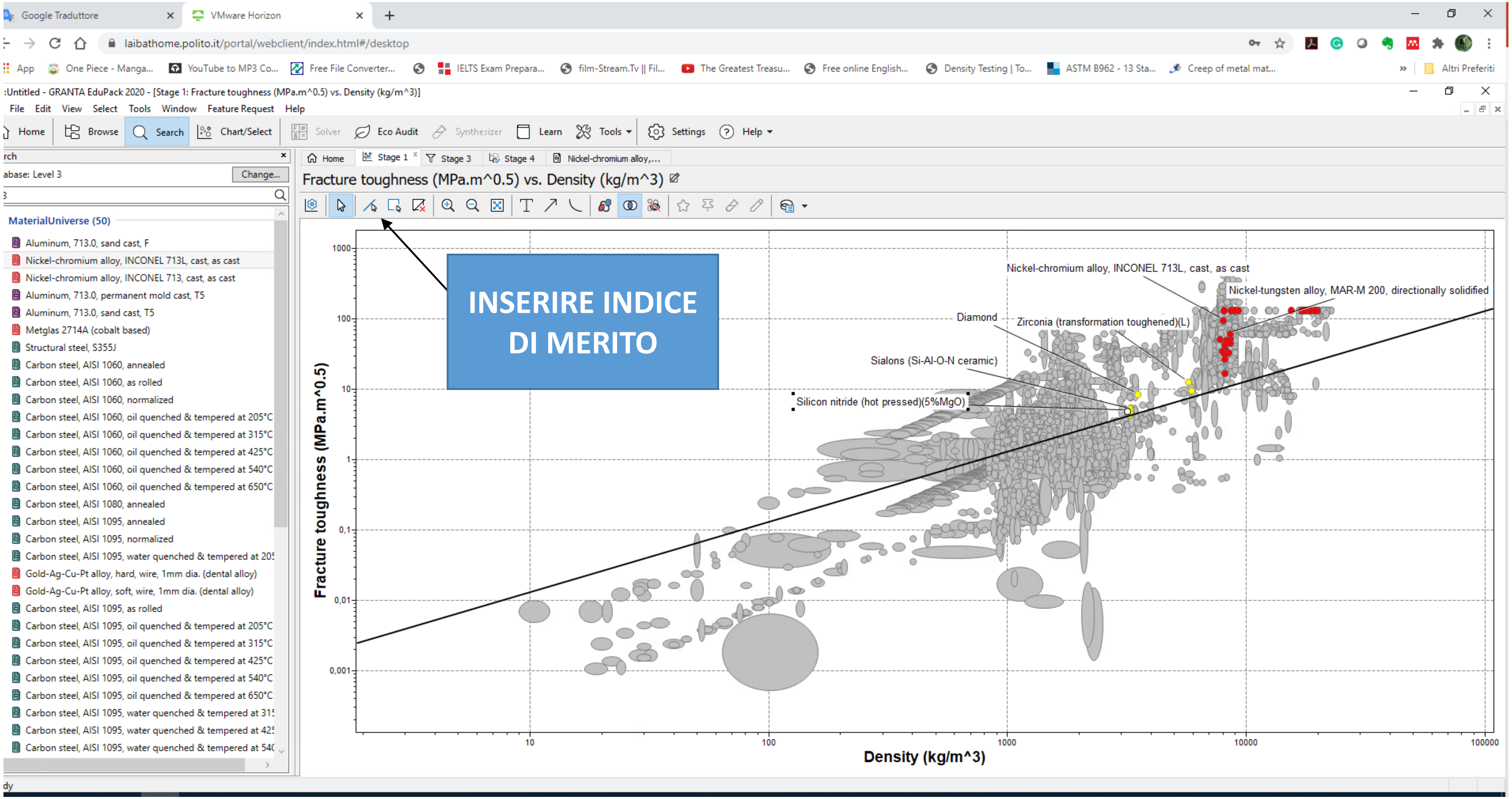
$$\omega < \frac{1}{R}\left(\frac{1}{\alpha\sqrt{\pi a^*}}\right)^{1/2}\left(\frac{K_{1C}}{\rho}\right)^{1/2} \qquad \text{(M7.3)}$$

The lengths R and a* are fixed, as is α. The safe rotational velocity ω is maximized by selecting materials with large values of

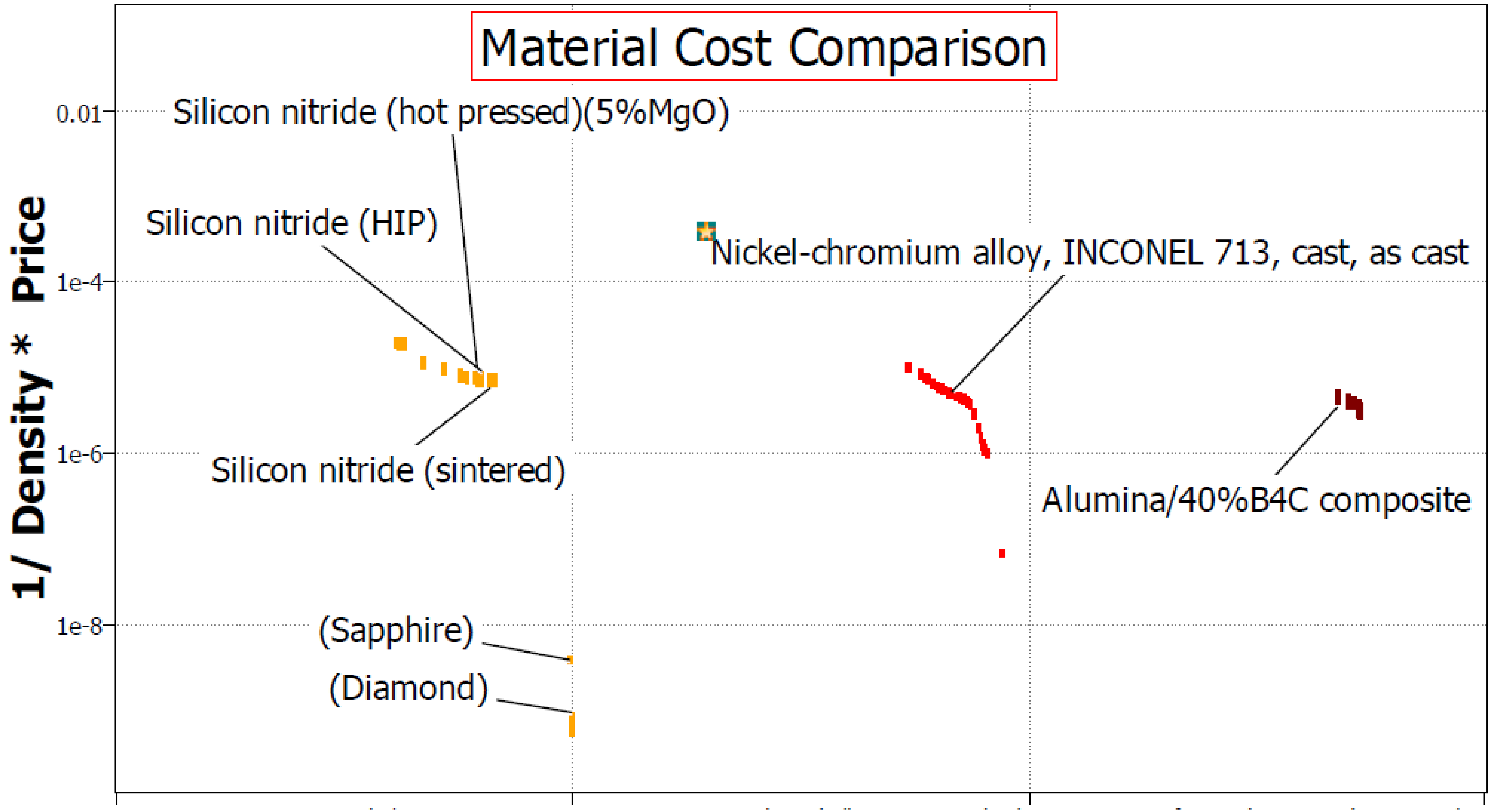
$$\boxed{M_1 = \frac{K_{1C}}{\rho}} \qquad \text{(M7.4)}$$



2° ESEMPIO



INSERIRE INDICE DI MERITO
Fracture toughness (MPa.m^0.5) vs. Density (kg/m^3)
Fracture toughness (MPa.m^0.5)
Density (kg/m^3)
Nickel-chromium alloy, INCONEL 713L, cast, as cast
Nickel-tungsten alloy, MAR-M 200, directionally solidified
Diamond
Zirconia (transformation toughened)(L)
Sialons (Si-Al-O-N ceramic)
Silicon nitride (hot pressed)(5%MgO)
MaterialUniverse (50)
Aluminum, 713.0, sand cast, F
Nickel-chromium alloy, INCONEL 713L, cast, as cast
Nickel-chromium alloy, INCONEL 713, cast, as cast
Aluminum, 713.0, permanent mold cast, T5
Aluminum, 713.0, sand cast, T5
Metglas 2714A (cobalt based)
Structural steel, S355J
Carbon steel, AISI 1060, annealed
Carbon steel, AISI 1060, as rolled
Carbon steel, AISI 1060, normalized
Gold-Ag-Cu-Pt alloy, hard, wire, 1mm dia. (dental alloy)
Gold-Ag-Cu-Pt alloy, soft, wire, 1mm dia. (dental alloy)
Carbon steel, AISI 1095, as rolled


Material Cost Comparison
0.01
1e-4
1e-6
1e-8
1/ Density * Price
Silicon nitride (hot pressed)(5%MgO)
Silicon nitride (HIP)
Silicon nitride (sintered)
Nickel-chromium alloy, INCONEL 713, cast, as cast
Alumina/40%B4C composite
(Sapphire)
(Diamond)