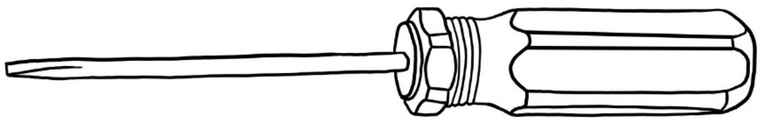
MATERIALISE

Screwdriver for George Future Technologies



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TECHNICAL SUMMARY

This report sets out the full process of material selection for a screwdriver for the client, George Future Technologies. The brief involves selecting a material that would function well and be perceived as ‘futuristic’. The report will focus on the material used for the shaft and drive tip.

The process starts with background research into existing products on the market to outline what material properties are most important and sets out some minimum criteria. The material selection process is split into four stages, with each stage narrowing down the materials from the level 1 group in EduPack. Stage 1 rules out any materials that have a Young’s Modulus and Vickers Hardness below the minimum criteria. Stage 2 involves maximising a performance index that considers the torsional force on the shaft. Stage 3 uses semantic differential scales to analyse how the material options are viewed by people. Finally, stage 4 focuses on the 3 remaining materials individually.

The finding of this report is that transparent Alumina (aka. Alon®) in combination with magnetised Stainless Steel would be a suitable material combination in answer to the brief, as it offers additional optical properties and functions that is not offered by any other material on the market.

CONTENTS

INTRODUCTION & BRIEF

This report will outline the stages of material selection and give a justified conclusion in response to the brief given by the client, George Future Technologies. The process of material selection will be limited to the central part of the screwdriver (i.e., the shaft, integrated with the drive tip). The final material selected will fit the product requirements both functionally and aesthetically.

The client, George Future Technologies, requires the selection of a new material to make a screwdriver that customers would consider to be 'futuristic', as this will be the unique selling point of the product. The brief can be summarised as such:

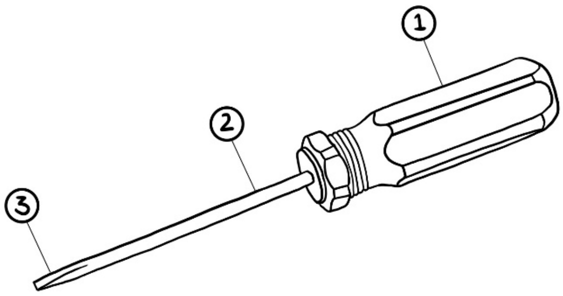
- Mechanically, the screwdriver must be able to withstand the stress applied to it to a standard that surpasses other screwdrivers on the market
- The material must be 'futuristic', whether that is aesthetically or because it can serve a function beyond what other screwdrivers can do.
- The product must be high-quality and up-market so as to appeal to professional tradespeople.
- The price of the material is not a concern. Customers should want to buy this product regardless of its price because it is so unique/ unparalleled by any other alternative.
- The choice of the material should be entirely unique, meaning that there is no other screwdriver on the market that is made of that material.

BACKGROUND RESEARCH

In this section, the report will define the parts of a screwdriver and their uses. Next, it will examine the materials used to make screwdrivers that are already on the market and analyse their material properties to help set out some minimum criteria.

Product Analysis (Screwdriver)

A screwdriver is made up of three parts [1]:



1. Handle – designed to be easily gripped by the user.
2. Shaft – much thinner than the handle, usually a few inches long.
3. Drive tip/bit – can be integrated into the shaft but can also be made detachable so the screwdriver can have multiple screwdriver heads (such as Philips or slotted).

This report will focus on both the main shaft material and the drive tip material, perhaps integrated together into one component.

Existing Product Research

Figure 1 - *STANLEY® CUSHION GRIP FLARED*

Stanley brand screwdrivers have a shaft made of low-alloy steel, which is plated with chrome and nickel to resist corrosion and prevent rusting. The drive tip is a different colour from the shaft and is magnetic in order to pick up screws and grip them more easily. The handle is made to be soft and easy to grip for more comfort and control. [2]

Figure 2 - *#1 COMBO-TIP DRIVER, 4-INCH FIXED BLADE*

Klein Tools makes screwdrivers with a precision-machined tip for accurate usage. The shaft and drive tip are made from steel that has been heat-treated to increase strength and longevity. [3]

Figure 3 - *WERA KRAFTFORM 334/355/6 SCREWDRIVER SET*

Wera designs ergonomic handles, made from a combination of smooth, hard material for 'high speed turning' and a material with higher friction for 'high torque transfer'. The tip is made from steel that has been treated with a laser to create a 'sharp-edged surface structure' in order to prevent slippage and increase hardness (up to 1000 HV 0.3). The material treatment means that less contact pressure is needed than normal. The shaft is made from a chrome-plated steel. [4]

The most common material for making the shaft of a screwdriver is **high-strength low-alloy steel** (plated with chrome). Outlined below are the typical material specifications that can be used to set out some minimum criteria similar to the current competition already on the market.

Table 1 Material properties of Low-Alloy Steel and Minimum Criteria

Material property	Value for Low-Alloy Steel	Minimum Criteria
Tensile Strength (MPa)	699 -1800	600
Hardness, Vickers (HV)	215 - 515	100
Young's Modulus (GPa)	200 - 210	100

MATERIAL SELECTION

Stage 1 : Using minimum criteria

For the first stage of material selection, the minimum criteria were used to identify which material families should be focused on. Using a minimum Young's Modulus of 100 GPa and a minimum Hardness of 100 HV. These properties are very important for the application of a screwdriver. The material must be able to withstand changes in length when under lengthwise tension or compression, and resist localised plastic deformation, especially at the drive tip as it will experience a lot of friction with the screw head.

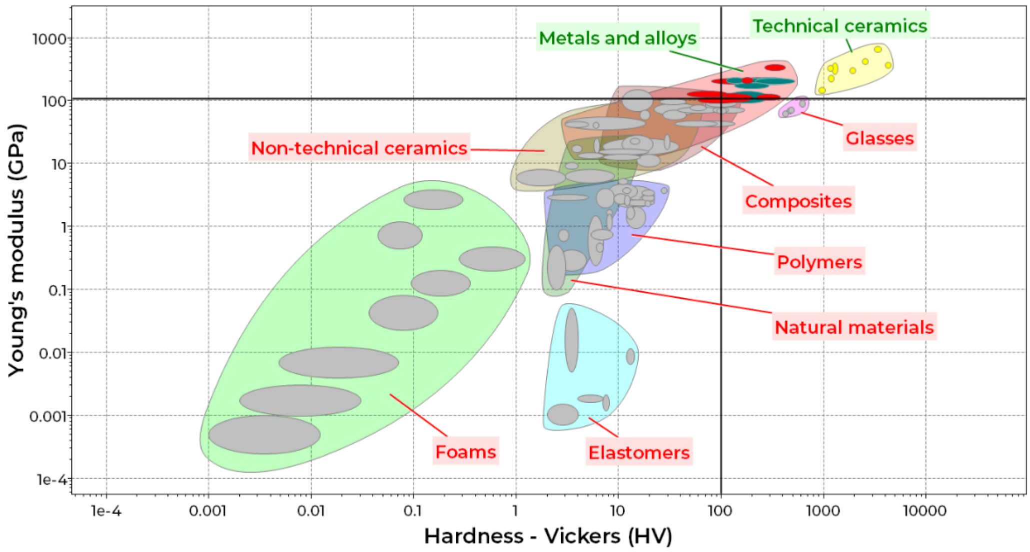


Figure 4 – *ASHBY PLOT SHOWING YOUNG'S MODULUS (GPa) AGAINST HARDNESS (HV) FOR ALL LEVEL 1 MATERIAL FAMILIES*

The whole of the ceramics family and part of the metals & alloys family passed this first stage, taking the group of possible materials from 100 to 23. More focused analysis can be done on these remaining materials.

Stage 2 : Using Performance Index

The next stage of selection involves maximising shear strength and minimising density. Shear strength is important as the shaft and drive tip will experience tortional force as a main source of possible deformation/failure. The density is also a significant factor to consider as a screwdriver is a hand-operated tool so should be as light as possible. A lower density will mean it can be used more easily by a wider range of people for a longer amount of time.

The Performance Index (P) τ_f= shear strength (Nm^{-2} or Pa), ρ = density (kgm^{-2})

$$P = \frac{\tau_f^{\frac{2}{3}}}{\rho}$$

The value of shear strength is directly proportional to tensile strength ($\tau_f = 0.6 * \sigma$ [5]) so performance index can also be:

$$P = \frac{\sigma^{\frac{2}{3}}}{\rho}$$

(derivation in appendix)

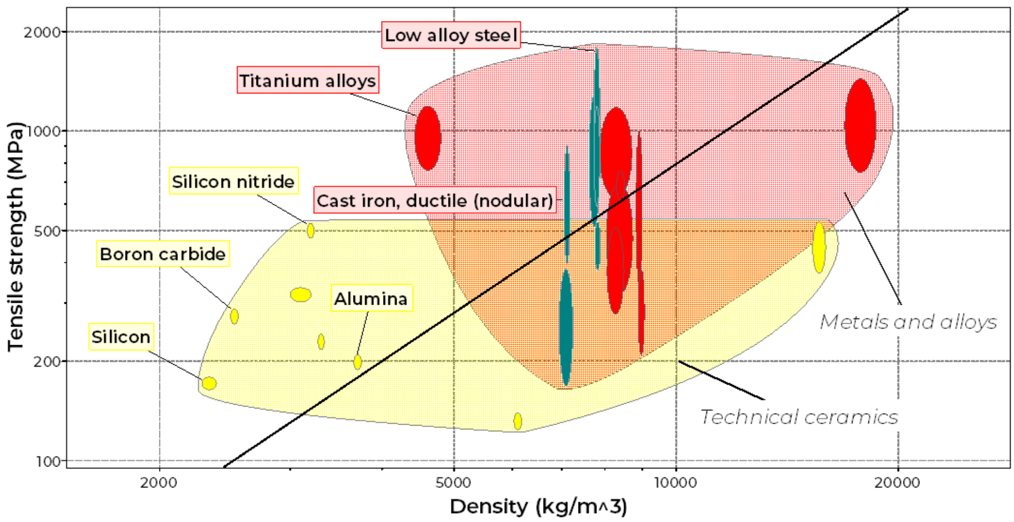


Figure 5 - *ASHBY PLOT SHOWING TENSILE STENGTH (MPa) AGAINST DENSITY (Kg/m^3) TO COMPARE THE PERFORMANCE INDEX OF CERAMICS AND METALS & ALLOYS*

Minimum Performance Index Value (as shown by selection line) : 0.0700

All materials below the selection line were ruled out since the performance index must be maximised. The table below shows the 16 remaining materials, ranked by their Index Value (calculated in EduPack).

Table 2 - *Performance index of the 16 remaining materials*

Material	Performance Index Value
Titanium alloys	0.021
Silicon nitride	0.0197
Boron carbide	0.0168
Silicon carbide	0.0151
Low alloy steel	0.0138
Silicon	0.0133
High carbon steel	0.0128
Medium carbon steel	0.0114
Aluminium nitride	0.0114
Stainless steel	0.0113
Nickel-based superalloys	0.011
Cast iron, ductile (nodular)	0.01
Nickel-chromium alloys	0.00924
Alumina	0.00924
Nickel	0.00789
Bronze	0.00727

Stage 3: Analysing semantics / subjective factors

In order to select a material that is perceived as 'futuristic', semantic differential scales are used to gauge how potential customers view a material. The factors that are most important at this stage are the quality, performance and how futuristic the materials are.

This analysis was done using 6 materials from the 16 remaining ones as many of them are indistinguishable from each other or are not widely known. Only materials that would produce well-informed and varied results are chosen. The factors were evaluated using a 1 to 10 scale, with a more suitable material having a higher score for every factor.

Table 3 - Average semantic differential scale scores for the 6 chosen materials

	Titanium Alloys	Silicon	Alumina	Bronze	Stainless Steel	Boron Carbide
Futuristic - Antiquated	7.6	6.5	7	4	7.3	6.7
High Quality - Low Quality	8	6	7.5	5.5	7.6	7.8
Durable - Flimsy	8.8	5.2	8	6	8.7	8.1
Elegant - Clumsy	6	3.7	6.3	3.2	7.6	5.6
Hard - Soft	8.4	4.3	7.8	6.1	7.9	8.3

(Full data in appendix)

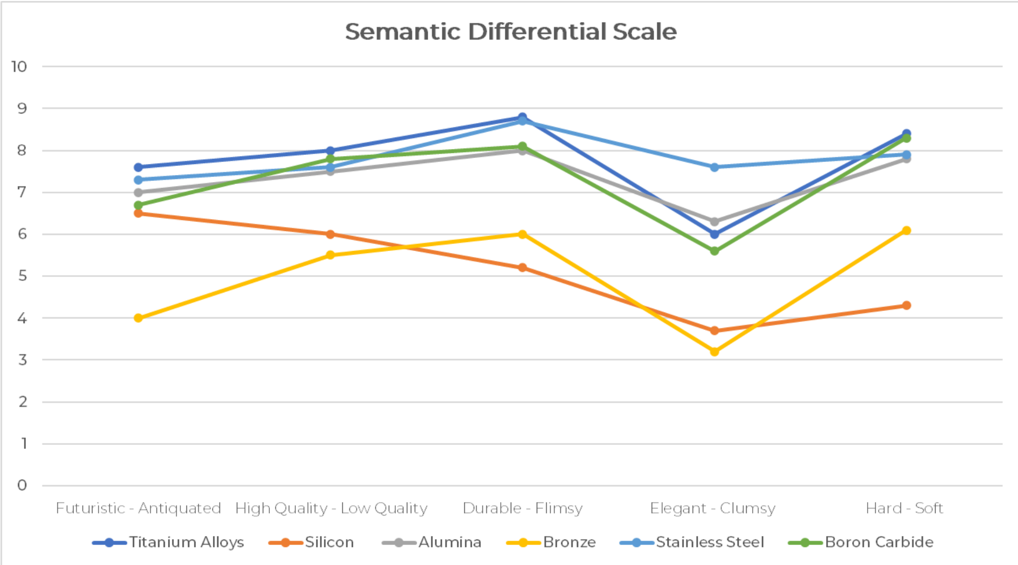


Figure 6 - SEMANTIC DIFFERENTIAL SCALE FOR THE 6 CHOSEN MATERIALS

From this analysis, the ideal materials to use would be Titanium Alloys, Alumina and Stainless Steel, as they seem to be perceived to be both futuristic and perform well.

Stage 4: Individual analysis of material options

Each of the 3 materials (Titanium Alloys, Alumina, and Stainless Steel) must now be analysed individually to identify any other special properties as well as downsides of their use so an informed decision can be made.

Material Option 1: Titanium Alloys

Titanium alloys are incredibly strong and resistant. The strength to weight ratio is already very impressive but can be made even better by forming it into a metal foam. The density would be reduced to a minimum of 1/5 of the original density [6]. This property could improve its perception of being futuristic, as it would mean the screwdriver is much lighter than expected.

Performance index of Titanium alloy foam = = **0.092**
(Using σ = 763 MPa and ρ = 4540/5 kg/m^3)

Material Option 2: Alumina

Alumina is also known as Aluminium Oxide (Al_2O_3) or Sapphire (in pure crystal form). It does not corrode easily, is very chemically stable and is electrically insulating. It can be quite brittle and has low impact resistance as it is a ceramic, however, if created correctly, it can form Alon®. Alon® is an optically transparent and particularly strong material. It can withstand the impact of 50calAPM2 rounds, is much harder than glass and has a tensile strength many times that of steel. It is much more expensive to manufacture than typical Alumina, but price is not an issue in this selection process. [7]

Performance index of Alon® = **0.213** (Using σ = 700 MPa and ρ = 3691 kg/m^3 [7])

Alon® could be perceived as very futuristic in that it is both optically transparent and durable. However, people may associate its transparency with brittleness. Advantages to it being transparent may be that the shaft does not block the view of what is being worked on and a light could be shone through the handle to improve visibility. The refractive index of Alon® is 1.79089 [8], so it is more optically dense than air. This means that total internal reflection will occur and the shaft will glow when a light is shone through it.

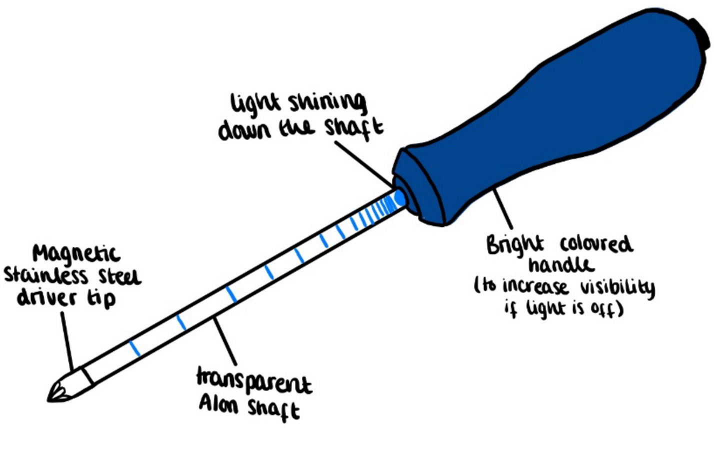
Material Option 3: Stainless Steel

Stainless steel is a type of Iron alloy, with the primary alloying element being chromium. It is relatively cheap. It resists corrosion, meaning any product made from it would be long-lasting. Another upside to stainless steel is its ability to be magnetised, which is not a property of any of the other 2 material options. However, it is not seen to be as futuristic and has a much lower performance index.

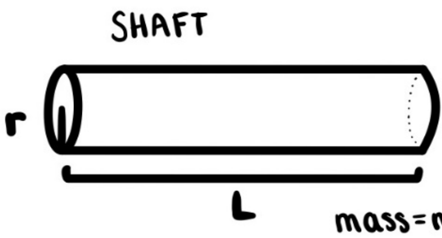
Performance index of Stainless Steel = **0.0113**

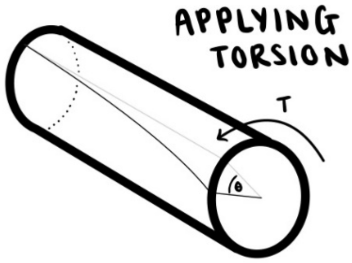
CONCLUSION

The chosen material is a combination of Alon® and Stainless Steel in order to combine to best parts of both their material properties. This chosen combination will mean that the screwdriver shaft is very hard, strong, transparent, with a drive tip that is visible, magnetic and precision machined. This combination of materials will be expensive, since Alon® is £11.25 per cubic inch, however, picking a cheap material is not the client's main priority. The addition of a light-up feature in the design will make the product even more futuristic and highlight the unique nature of the transparent shaft.



Derivation of Performance Index





mass = m, density = ρ

$$\frac{\tau}{r} = \frac{T}{J} \qquad J = \frac{\pi r^4}{2}$$

Shear stress at radius r [Nm⁻²] (τ); Applied torque [Nm] (T); Radius [m] (r); Polar second moment of area [m⁴] (J)

(for solid circular section)

Elastic torsion formulae from formulae sheet

COMBINING THESE EQUATIONS...

$$\tau = \frac{2T}{\pi r^3}$$

...and at fracture stress, τ_f ...

$$\tau_f = \frac{2T}{\pi r^3}$$

Replace with $\sqrt{\frac{m}{\pi L \rho}}$

$$\tau_f = \frac{2T}{\pi\left(\frac{m}{\pi L \rho}\right)^{2/3}} \Rightarrow m = \underbrace{(2T)^{2/3} \cdot \pi^{1/3} \cdot L}_{\text{other properties + constants}} \cdot \underbrace{\left(\frac{\rho}{\tau_f^{2/3}}\right)}_{\text{material properties}}$$

MINIMISE (m) — MINIMISE ($\frac{\rho}{\tau_f^{2/3}}$)

$\Downarrow$

Performance Index (MAXIMISE): $\boxed{P = \frac{\tau_f^{2/3}}{\rho}}$

PLOTTING PERFORMANCE INDEX ASHBY PLOT

$$P = \frac{\tau_f^{2/3}}{\rho} \longrightarrow P = \frac{\sigma^{2/3}}{\rho}$$

replace τ_f with σ
as σ is a property in EduPack
and $\tau_f \approx 0.6 \times \sigma$ $(\tau_f \propto \sigma)$

Taking logs and rearranging...

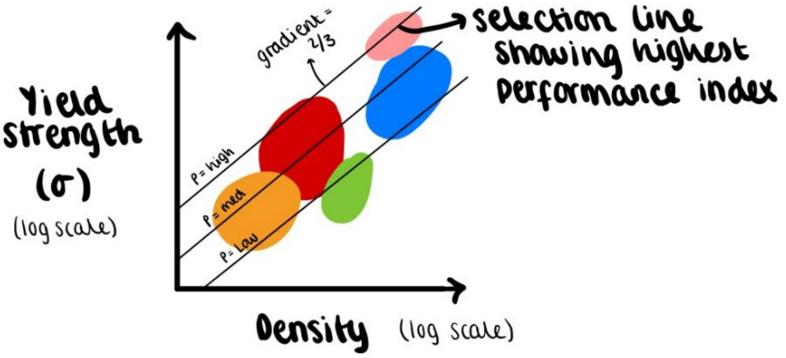
$$\log\sigma = \frac{3}{2}\log\rho + \underbrace{\frac{3}{2}\log P}$$

$$y = (m \cdot x) + c$$

c → higher y-intercept = larger performance index

m → selection line should have a gradient of $3/2$

Quick Sketch of Ashby Plot...



Full data for semantic differential scale

Material 1 - Titanium Alloys

	Person 1	Person 2	Person 3	Person 4	Person 5	Person 6	Person 7	Person 8	Person 9	Person 10	Average
Futuristic - Antiquated	8	7	8	6	8	9	10	7	6	7	7.6
High Quality - Low Quality	7	8	9	8	10	6	7	8	9	8	8
Durable - Flimsy	9	10	10	8	9	7	9	8	8	10	8.8
Elegant - Clumsy	6	7	6	8	4	5	6	7	5	6	6
Hard - Soft	10	9	8	7	8	10	9	8	7	8	8.4

Material 2 - Silicon

	Person 1	Person 2	Person 3	Person 4	Person 5	Person 6	Person 7	Person 8	Person 9	Person 10	Average
Futuristic - Antiquated	7	8	6	7	4	8	6	8	5	6	6.5
High Quality - Low Quality	6	7	8	5	6	4	7	5	6	6	6
Durable - Flimsy	3	4	5	6	5	6	4	6	7	6	5.2
Elegant - Clumsy	4	3	5	4	1	4	5	4	3	4	3.7
Hard - Soft	3	5	4	6	5	4	5	3	4	4	4.3

Material 3 - Alumina

	Person 1	Person 2	Person 3	Person 4	Person 5	Person 6	Person 7	Person 8	Person 9	Person 10	Average
Futuristic - Antiquated	6	7	7	8	9	6	7	5	7	8	7
High Quality - Low Quality	7	8	9	6	7	5	8	7	9	9	7.5
Durable - Flimsy	7	8	9	7	8	8	9	8	8	8	8
Elegant - Clumsy	6	5	7	6	8	7	6	6	6	6	6.3
Hard - Soft	7	8	6	7	8	10	9	8	7	8	7.8

Material 4 - Bronze

	Person 1	Person 2	Person 3	Person 4	Person 5	Person 6	Person 7	Person 8	Person 9	Person 10	Average
Futuristic - Antiquated	4	5	3	4	5	6	3	4	2	4	4
High Quality - Low Quality	5	6	7	5	6	4	7	6	5	4	5.5
Durable - Flimsy	6	7	5	4	7	6	8	6	6	5	6
Elegant - Clumsy	2	3	4	3	5	2	3	3	5	2	3.2
Hard - Soft	6	7	5	4	6	7	8	7	6	5	6.1

Material 5 - Stainless Steel

	Person 1	Person 2	Person 3	Person 4	Person 5	Person 6	Person 7	Person 8	Person 9	Person 10	Average
Futuristic - Antiquated	7	6	7	9	8	7	8	6	7	8	7.3
High Quality - Low Quality	8	7	8	6	7	9	8	9	7	7	7.6
Durable - Flimsy	8	9	8	7	9	10	9	10	8	9	8.7
Elegant - Clumsy	7	6	7	8	9	8	7	8	7	9	7.6
Hard - Soft	6	8	9	7	8	9	8	9	8	7	7.9

Material 6 - Boron Carbide

	Person 1	Person 2	Person 3	Person 4	Person 5	Person 6	Person 7	Person 8	Person 9	Person 10	Average
Futuristic - Antiquated	7	6	6	6	5	6	8	8	7	8	6.7
High Quality - Low Quality	6	7	8	9	8	9	7	8	9	7	7.8
Durable - Flimsy	7	8	6	9	10	9	8	7	8	9	8.1
Elegant - Clumsy	5	6	7	5	6	5	6	7	5	4	5.6
Hard - Soft	8	8	9	8	7	8	8	9	9	9	8.3

EduPack Tasks

Task One

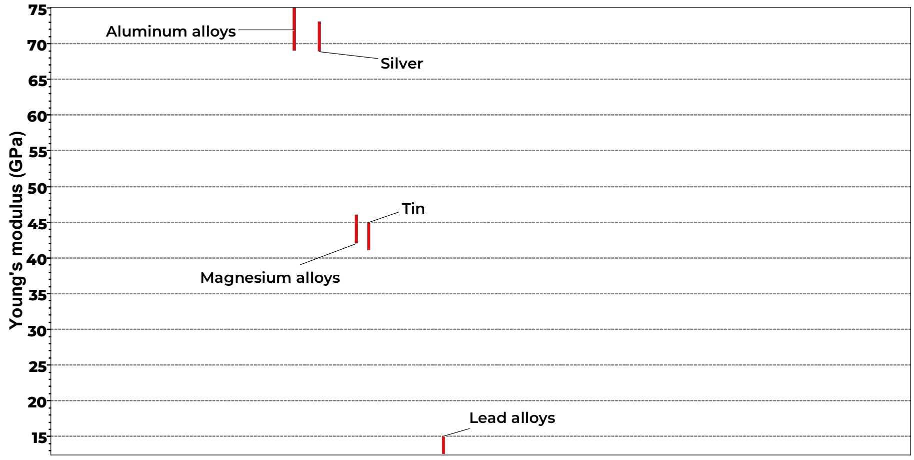


Figure 7- *BAR CHART SHOWING ALL LEVEL 1 METALS, ALLOYS, POLYMERS AND ELASTOMERS WITH YOUNG'S MODULUS VAUES BETWEEN 5 - 70 GPa*

Table 4 - *Young's Modulus of all relevant materials*

Material	Young's Modulus (GPa)
Aluminium alloys	69 – 74
Silver	68.9 – 73.1
Magnesium alloys	42 – 46
Tin	41 – 45
Lead alloy	12.5 – 15

Task Two

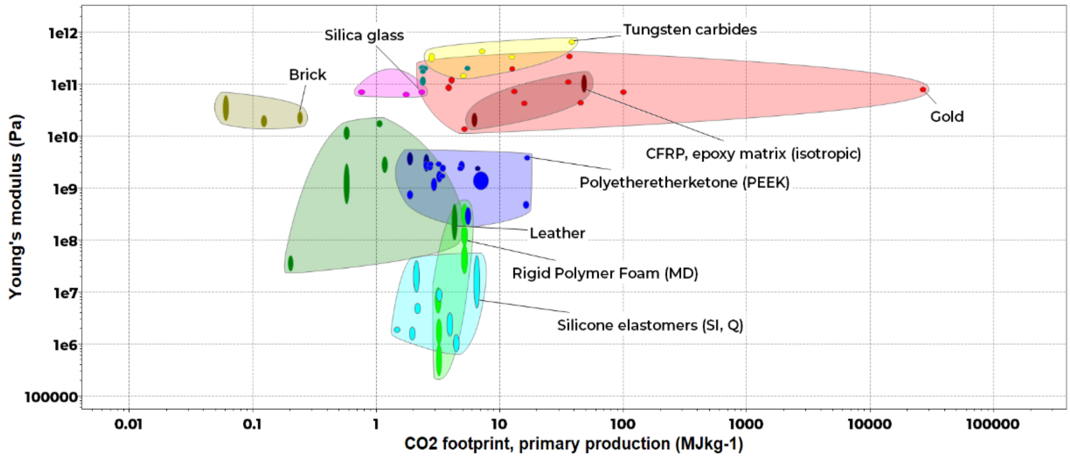


Figure 8 - *ASHBY PLOT SHOWING YOUNG'S MODULUS (Pa) AGAINST CO2 FOOTPRINT (MJkg-1) FOR ALL LEVEL 1 MATERIALS*

Table 5 - *Materials with the highest CO2 footprint from each material family*

Material	Material family	CO_2 Footprint ($MJkg^{-1}$)
Brick	Non-technical ceramics	0.229 – 0.252
Silica Glass	Glass	2.2 – 2.43
Leather	Natural Materials	4.08 – 4.5
Rigid Polymer Foam (MD)	Foams	4.9 – 5.4
Silicone Elastomers	Elastomers	6.2 – 6.83
PEEK	Polymers	15.9 – 17.5
Tungsten Carbides	Technical Ceramics	36.2 – 39.9
CFRP Epoxy Matrix	Composites	45.8 – 50.5
Gold	Metals and Alloys	25500 - 28100

Task Three

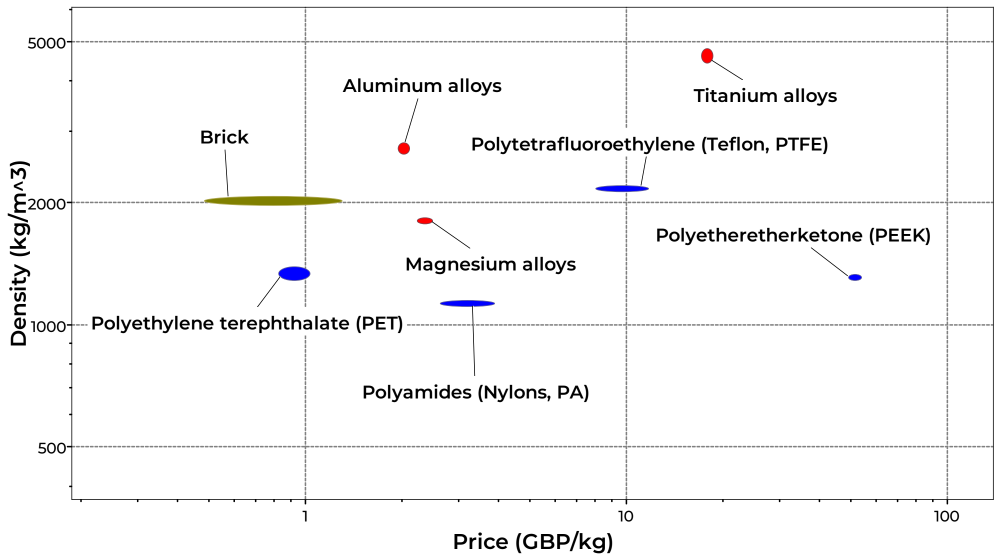


Figure 9 *- ASHBY PLOT SHOWING DENSITY (kg/m^3) AGAINST PRICE (GBP/kg) FOR ALL LEVEL ONE MATERIALS WITH A DENSITY BETWEEN 500-5000 kg/m^3, COST BETWEEN 0.5-50 £/kg, A YOUNG'S MODULUS < 100 GPa, AND A MELTING TEMPERATURE > 200 ∘C*

Table 6 *- Prices of all relevant materials*

Material	Price (GDPkg^{-1})
Brick	0.484 – 1.29
PET	0.827 – 1.03
Aluminium Alloys	1.94 – 2.1
Magnesium Alloys	2.23 – 2.48
Polyamides (Nylons, PA)	2.63 – 3.88
Teflon / PTFE	8.03 – 11.7
Titanium Alloys	17.2 – 18.6
PEEK	49.2 – 53.9

Task Four

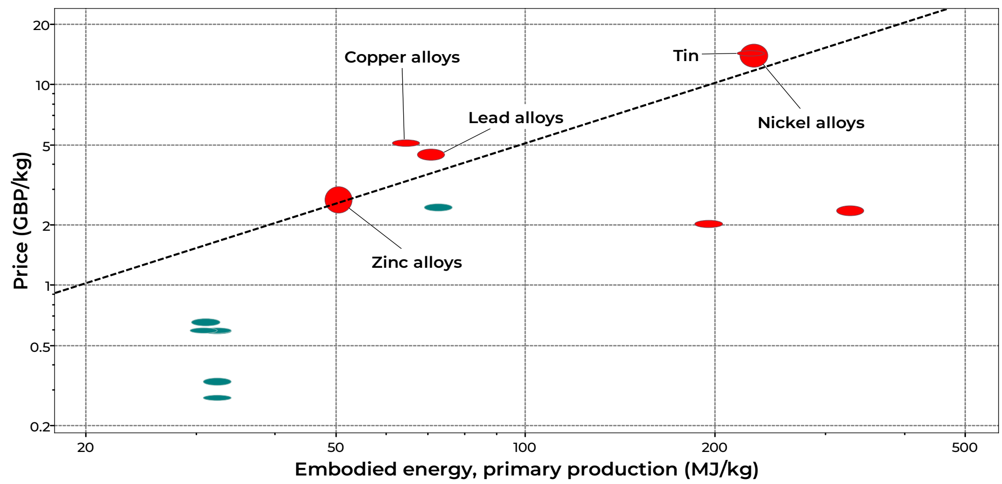


Figure 10 *- ASHBY PLOT SHOWING PRICE (GBPkg^{-1}) AGAINST EMBODIED ENERGY (MJkg^{-1}) FOR ALL LEVEL 1 CASTABLE ELECTRICAL CONDUCTORS WITH A TENSILE STRENGTH >10 MPa*

Table 7 *- Price, Embodied Energy and Performance index of all materials above Zinc*

Material	Price (GBPkg^{-1})	Embodied Energy (MJkg^{-1})	Performance Index - Price/Embodied Energy (GBPMJ^{-1})
Tin	14.1 – 14.6	217 - 239	0.0590 – 0.0673
Nickel Alloys	12.2 – 15.8	219 - 242	0.0504 – 0.0721
Lead Alloys	4.24 – 4.77	67.3 – 74.2	0.0571 – 0.0708
Copper Alloys	4.94 – 5.3	61.4 – 67.7	0.0734 – 0.0863

Task Five

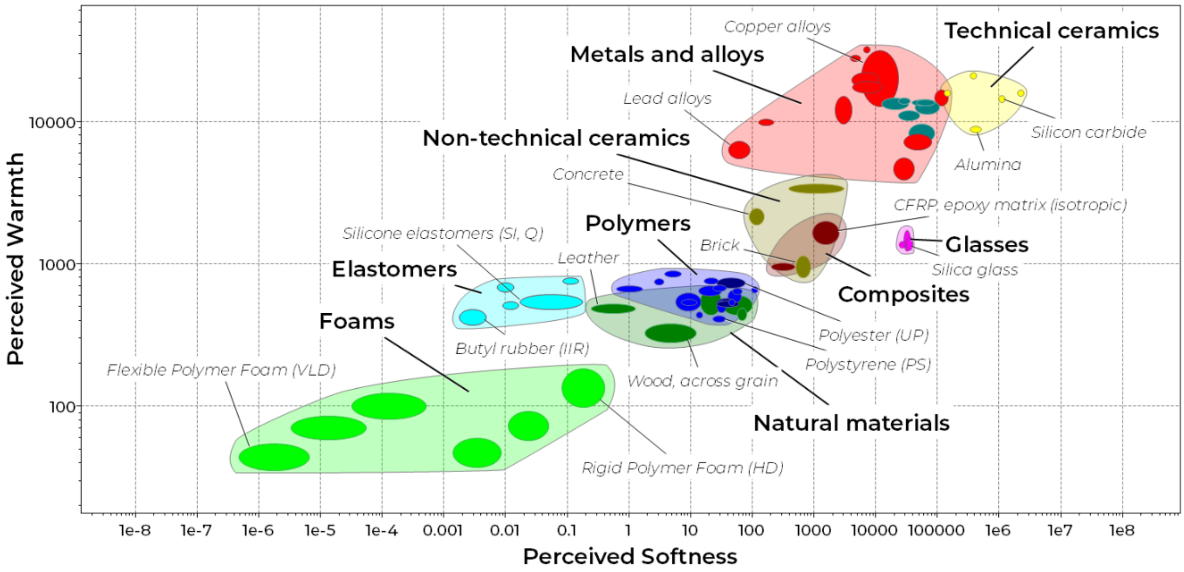


Figure 11 - ASHBY PLOT SHOWING PERCIEVED WARMTH, (=($\rho\lambda C_p$)$^{1/2}$) AGAINST PERCIEVED SOFTNESS (=EH) FOR ALL LEVEL 1 MATERIALS

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All other material data (presented in tables and Ashby plots) was obtained from CES EduPack.