REVENG Report

Heat Gun

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Technical Summary

This report documents the reverse engineering of a budget heat gun. Firstly, the product was disassembled into its individual components by using screwdrivers, hand saws and pliers. Each component was then weighed, subjected to polymer identification testing if necessary and then documented in order to form a bill of materials. The manufacturing method and primary materials were noted and then the overall product was submitted into the CES EduPack Eco Audit tool along with the calculated transport and use statistics. This calculated the total embodied energy and yearly CO2 product footprint for the heat gun, as well as the individual values for each component. This allowed for the highest contributing components and materials to be highlighted and selected for replacement. The components and materials chosen were the ABS outer casing and the low carbon steel screws – the screws were chosen due to their poor hardness resulting in the heads stripping during the disassembly and outer casing due to its poor contribution to the sustainability of the product. Using the CES EduPack level 2 database, new materials for the outer casing were selecting by inputting filters that had the same performance characteristics as ABS but an improved CO2 footprint and embodied energy values. The ABS was chosen to be replaced by PET and the low carbon steel to be replaced with low alloy steel.

Contents

Introduction

This report aims to document and justify the process of reverse engineering the Homidic Mini Heat Gun. The client – Lisa Simpson Power Tools – is a design company aimed at producing long-lasting, high quality, sustainable and affordable products. They recognise the detrimental impact that cheap, mass produced products can have on the environment and aim to combat this through the use of low cost yet sustainable materials in their products. They commissioned a teardown and report on a popular hobbyist's heat gun to help inform on their own design.

Firstly, the general market for heat guns is discussed and their applications in order to better understand the material requirements. Next, the method of disassembly is discussed along with comments on how the product was assembled. The results of the teardown are documented in a bill of materials and this information was inputted into the CES Edupack Eco Audit tool to calculate the products sustainability factors. Lastly, using the information gathered on the applications, current materials and manufacturing methods used and the environmental impact from such, the product was reverse engineered to produce a design that follows the characteristics required by the client.

Background

General Information about Heat Guns:

Heat guns are versatile tools that operate by emitting a stream of hot air through a nozzle which can be adjusted in temperature for different tasks. This is achieved by a small fan blowing air through an adjustable electric heating element. They are typically used in applications such as stripping paint, thawing pipes, shrinking heat shrink tubing, bending and moulding plastics and applying vinyl wraps. There are two different types of heat guns: electric and gas-powered. Electric heat guns are the most common for domestic applications due to their ease of use and safe operation. Gas-powered heat guns are favoured in more commercial settings where operators are trained in their use and also in situations when an electricity supply is not readily available. Heat guns differ from other tools such as blowtorches as they provide a more delicate and controlled heat source.

Makita HG5030K/2 (1)

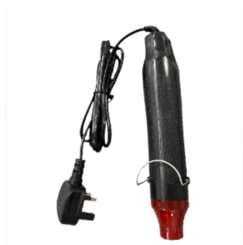
1600W

£69.99

HellermannTyton CHG900 (2)

P445 Gas Cartridges

£238.66



Homidic Mini (3)

300 W

£11.99

Common Materials and Manufacturing Methods:

The main components of an electric heat gun (as this is the type of heat gun that is used for the product breakdown) include: outer casing, electric heating element, fan, motor and nozzle.

Table 1: Typical heat gun components, materials and manufacturing methods

Component	Typical Material and Properties	Standard Manufacturing Method
Outer Casing	**ABS** due to its high rigidity and impact resistance to withstand rough use in a construction environment.	Injection Moulded
Electric Heating Element	**Nickel Chromium Alloy:** Used for its high electrical resistance in order to heat up rapidly.	Wire Drawing
Fan	**ABS:** Used for its ability to withstand high temperatures without deforming	Injection Moulding
Nozzle	**Stainless Steel** due to its durability, resistance against corrosion and ability to handle high temperatures.	Forming processes such as bending, rolling and pressing

Our Product for Reverse Engineering:

This product is a Homidic Mini 300W Multi-Function Electric Heat Tool, priced at £11.99 on Amazon. It features an ABS outer casing with a rhombus texture finish for improved grip, as well as a stainless-steel internal casing for the heating element. It can reach around 200°C within a few seconds. It does not offer a variable temperature setting but does come with a 12-month warranty. The heat gun is approximately 225 x 47 mm and it comes with a 2 m long cable. It is designed for multiple applications including embossing powder, heat shrink, clay, fast-drying paint, glue, rapid thawing and seal wax patterning.

These features and the price band set the Homidic Mini at the lowest level of quality for heat guns. It is designed to be cheap to manufacture and can therefore provide a cheap alternative for DIY hobbyists and crafters who do not require the more complex functions and heat levels that a more expensive heat gun would offer. However, this push for the cheapest possible manufacturing method results in a lack of consideration for the product's embodied energy and CO2 levels, as well as its product lifespan and end of life recyclability. By reasoned reconsideration of the materials and manufacturing processes, the team believe that the sustainability of the product can be greatly improved, whilst keeping the manufacturing costs down.

Disassembly Method

After receiving the product, the team began by removing the product from the packaging. Inside the cardboard box, there was a layer of packing foam, the heat gun and a user manual. The team then connected the heat gun to a power supply and tested its functionality. It had strong ergonomic features such as the outer casing's shape and texture. The stream of hot air produced was mildly strong, enough to function as a hobbyist's tool. After removing the power supply to the product, the team then selected the correct screwdriver head as shown is part 2a of the appendix. The outer casing was removed by means of 4 small self-tapping screws. After removing three of the screws, the fourth one had to be snapped as the head got stripped by the screwdriver, indicating a cheap alloy used.

Inside, there was a stainless-steel shroud covering the heating element, the motor housing, as well as the red polymer nozzle cover. These internal parts were not secured in place directly, instead held in place by the clamshell effect of the outer casing. The casing had small protruding sections inside to hold each internal component securely in its correct position. The team then removed the internal parts and cut the wires and switch as shown in part 2b of the appendix. The fan assembly was entirely press fit and so the fan was pulled from the motor shaft and the fan housing was pulled from the motor. There was a 4-bridge rectifier connected to the motor (as shown in part 2e) to convert the AC power supply into DC.

The stainless-steel casing for the heating element was also a push fit with the steel nozzle, however this had been machine pressed into position and could not be separated. Fortunately, the heating element simply pulled out of the back. This consisted of two composite (likely Mica) sheets with cutouts for the coil of wire as shown in part 2f. These were separated by a moulded steel cross and then a coiled nichrome wire was wrapped around. The composite sheets had brass eyelets in for the nichrome wire to attach to. Neither the wire, filament support nor filament divider were mechanically fastened together suggesting that the assembly had been optimised for minimal cost.

The plug was cut open using a hacksaw as shown in part 2d as it had been over moulded as a solid component. Typically, a plug is formed by two halves which are held together by screws. Again, this shows that the product was designed to be as cheap as possible to manufacture. Inside the plug were simply the wires connecting the plug outlet to the main product cable. There was no transformer used in the product. The fuse was on the outside of the plug, providing a quick and efficient replacement but also offering little protection for it.

Each component was then weighed on a mass balance and its mass noted. Using a polymer identification flowchart, technical data for the product, polymer identification symbols and the help of lab technicians, the materials and manufacturing processes used for each component were identified and noted. Many of the polymers had to be burnt for flame tests as shown in part 2h. This was conducted under a fume hood to ensure that any chemicals released were removed from the enclosed space inside the lab. Lastly, the full disassembly was presented onto an A3 white card, as shown in part 1 of the appendix.

Discussion:

Bill Of Materials

After the product disassembly, a full bill of materials was produced which is shown in part 3 of the appendix. Cells labelled with 'E' represent a best estimate and those labelled with 'C' represent information that has been confirmed. The quantity, materials and masses for each part were entered into CES EduPack which returned the embodied energy and CO2 footprint.

Table 2: A summarized bill of materials

Part No	Part Name	Quantity	Primary Material	Primary Manufacturing Process	Mass per unit / g	Material Embodied Energy / MJ	Material CO2 footprint / kg
1	Outer Casing	1	ABS (C)	Injection Moulding (C)	64	4.3	0.18
2	Nozzle	1	Polycarbonate (E)	Injection Moulding (E)	10	1.2	0.059
3	Stand	1	Mild Steel (E)	Extrusion Moulding (E)	4	0.085	0.0065
4	Filament Casing	1	Stainless Steel (C)	Roll Forming (C)	28	1.4	0.11
5	Insulator	1	FRP (E)	Resin Spray-up (E)	2	0.2	0.012
6	Filament Support	1	FRP (E)	Compression Moulding (E)	8	0.81	0.048
8	Filament	1	Nickel Chromium (C)	Wire Drawing (C)	1	0.18	0.01
10	Motor Shell	1	Low Carbon Steel (E)	Die Casting (E)	26	0.55	0.042
12	Motor Top	1	PVC (E)	Injection Moulding (E)	6	0.38	0.017
13	Fan Housing	1	Polyethylene (E)	Injection Moulding (E)	4	0.32	0.0074
14	Fan	1	Polyethylene (E)	Injection Moulding (E)	2	0.16	0.0037
15	Switch	1	PVC (E)	Injection Moulding (E)	2	0.13	0.0055
16	Cable Coating	1	PVC (C)	Over moulding (C)	28	1.8	0.077
17	Wires	2	Copper (C)	Wire Drawing (C)	5	0.2	0.013
18	Plug	1	UF (C)	Injection Moulding (E)	56	4.2	0.18

Overall, 8/20 of the components were made from metal, 8/20 were manufactured from polymers and 4/20 were composite materials such as GFRP. The most used polymer by mass was ABS and the most used metal was mild steel despite the heat gun being advertised as having a 'stainless steel interior'.

Material and Manufacturing Process Analysis

The two-part outer casing was made from ABS as confirmed by the product Amazon listing as well as through the polymer identification flowchart. It was likely formed through injection moulded due to the interior having ejector pin marks (as shown in part 4a of the appendix) and also due to the complex geometry of the overall shape as well as the internal struts. It had been post-processed to achieve the rhomboid texture on the outside to improve grip. The inside was left rough with mould markings on, in order to reduce costs. The struts on the inside perform two functions: improve the rigidity and the strength of the outer casing to allow for thinner walls to reduce material costs, as well as help position the internal components correctly inside.

Injection moulding is an optimal manufacturing process for large production runs. It has a high startup cost in order to produce the moulds, however, once these have been created, it allows for high accuracy, high speed and low unit cost manufacturing. For these reasons, as well as for its ability to produce a high-quality surface finish without the need for further post processing, makes it an ideal method for manufacturing the polymer components. Due to the high initial cost per part for injection moulding, as well as the large amount of components that were injection moulded in the product, it suggests a production run of at least 2000 in order to sufficiently cover the startup costs.

Polycarbonate was most likely used for the nozzle. The material needed to have a high heat resistance as it was shielding the stainless-steel internal nozzle, as well as high toughness and hardness to resist any impacts that could damage the stainless-steel nozzle – making polycarbonate an ideal option. The nozzle has a shiny, red, translucent appearance which is often associated with dyed polycarbonate. This component was also likely injection moulded due to its complex shape and high-quality surface finish which also reflects the use of PC due to its high flow characteristics allowing it to fill the mould completely before it solidifies.

The internal filament casing comprised of a stainless-steel nozzle compression fit onto a mild steel casing as shown in part 4b of the appendix. The stainless-steel nozzle likely began as a thin-walled tube which was then placed partially over the steel casing and a mould inserted inside. A press then formed the stainless steel into the nozzle shape whilst compression fitting it to the steel casing. This rapid manufacturing method allows for an extremely low unit cost whilst maintaining consistency and high dimensional accuracy. Stainless steel was used due to its high heat resistant properties, as well as its resistance to oxidation (maximum service temperature of 870°C (4)) as the heat gun is a product which will endure many high heat cycles.

Inside the steel casing, a layer of fibre reinforced polymer was used as an insulator to protect the steel from the red-hot nichrome wire heating filament. FRP is an excellent insulator as it has a very low thermal conductivity of 0.58 W/mK (5). Despite this, there were some visible burn marks from where the wire had been contacting it directly, as can be seen in part 4c of the appendix.

The filament support was formed from another fibre reinforced polymer but was likely compression moulded to create the high rigidity found in the part. It also had to be an excellent thermal insulator as it acted as a body for the heating filament to wrap around. The filament itself was a nichrome wire which is a common alloy to use due to its high electrical resistivity ($1.1 * 10^{-6}$ Ωm) (6). A high resistivity is beneficial as it can heat up rapidly when connected to an electricity supply. The nichrome wire along with the copper wire for the cable were likely formed by wire drawing processes as it can produce wires with consistently accurate diameters, as well as the process increasing the tensile strength of the metal through cold working during the process.

Both the fan housing and fan were found to be manufactured from polyethylene by following the polymer identification flowchart. Both parts softened under a soldering iron, floated in water and then burnt rapidly with a blue flame with a yellow tip. This material was used due to its low cost and low density – which is beneficial in handheld devices and especially for fan blades to reduce the load on the motor. PE can also be easily moulded through processes such as injection moulding which was most likely to be the manufacturing process used.

The switch and cable coating were confirmed to be made from PVC as samples of both softened under a soldering iron, sunk in water and had a self-extinguishing yellow flame with green edges that did not drip. PVC was used due to its durability and chemical resistance which is important for components on the exterior of the product as they can encounter many different substances especially in the applications of a heat gun. The switch housing was likely injection moulded but the cable coating was estimated to have been over moulded which is a common process for coating copper wires in a polymer.

Eco Audit

After analysing each of the components and noting their materials and manufacturing methods used, they were entered into the CES Edupack Eco Audit tool in Level 2. The motor was approximated as two components: the motor housing made from low carbon steel and the commutator made from iron. The plug and fuse were inputted as an inlet plug. It was given a product life of 1 year, converting electrical energy to thermal energy at a rate of 300 W, as described by the product data. Its usage was estimated as 3 days a years and 0.17 hours per day (10 minutes). It was assumed that most of the components were manufactured and assembled in Shanghai as the product states that it is made in China. Therefore, the shipping routes between Shanghai port and Thamesport were researched and found to be approximately 22000km (7). The final journey was estimated to be 70 miles to London on a 6-axle truck.

The main metal and thermoplastic components were inputted to be recycled at the end of the product life and the rest go to landfill. Similarly, the main components such as the outer casing and stainless-steel filament casing were inputted to be manufactured from the typical % of recycled material. Whilst smaller components such as the filament divider were said to be virgin material.

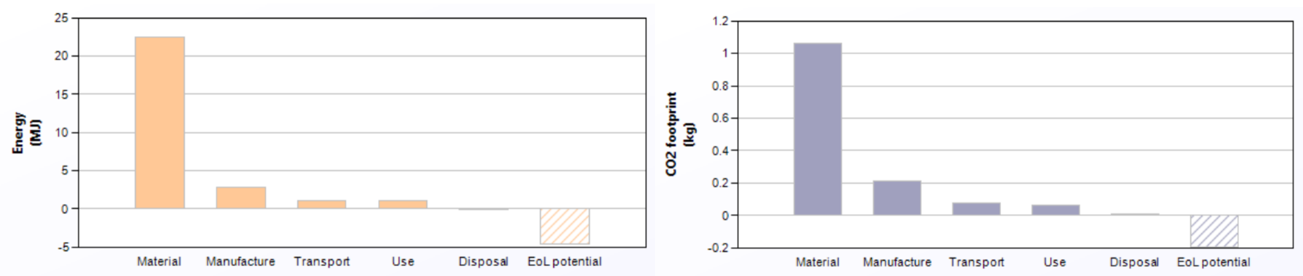


Figure 1: Graphs to show the energy analysis and the CO2 footprint of the product

As shown by the graphs, the overall product's embodied energy is 27.7 MJ per year of use and it's CO2 footprint is 1.42 kg per year. Most of the embodied energy (81.4%) and CO2 emissions (75%) arise from the materials including raw extraction, transportation from the mine, as well as processing operations. The components with the highest contributions to the embodied energy from their materials are the outer casing (26.6%), the plug (28.8%), the filament casing (6.4%) and the nozzle (3.5%). By redesigning the product to incorporate materials with lower polluting characteristics, the overall product sustainability can be greatly improved. In comparison to the materials, the manufacture, transport, use and disposal of the product account for only 18.6% of the embodied energy and so improvements in these areas will have a small effect on the overall product sustainability.

Reverse Engineered Solution

After analysing the components of the heat gun and calculating which contribute the most to the embodied energy and CO2 footprint, they were re-engineered to be manufactured from different materials to improve the sustainability. The plug had the highest contribution however as this is a standardised component with strict regulations on materials and designs, this was left unchanged. The next highest contributor was the ABS outer casing. To select an alternative material, the following constraints were inputted into level 2 CES Edupack:

- Maximum embodied energy of 88.9 MJ/kg and CO2 footprint of 3.41kg/kg in primary production
- Maximum embodied energy of 19.7 MJ/kg and CO2 footprint of 1.47 kg/kg in polymer moulding
- Minimum Young's Modulus of 2.07 GPa
- Minimum tensile strength of 37.9 MPa
- Minimum maximum service temperature of 50°C
- Minimum fracture toughness of 1.46 MPa(m)^0.5
- Maximum density of 1.5e3 kg/m^3
- Maximum price of 1.9 GBP/kg
- Moldability of at least 4

These factors ensure that the filtered materials will perform at least as well, cost no more and be more sustainable than ABS. The following Ashby Plot was produced.

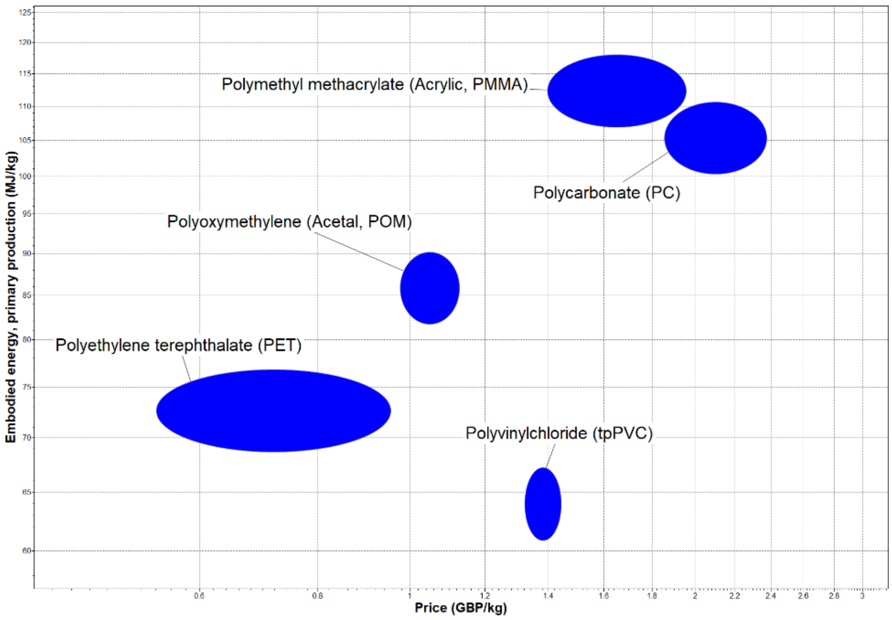


Figure 2: Ashby plot showing the remaining materials after the filters

Due to the combination of the lowest cost and lowest embodied energy, PET was shown as the optimum material to replace ABS. Not only does it feature comparable properties to ABS as inputted into the filter, but it is also chemically resistant to water and many other solvents which is beneficial in a construction environment. It is one of the most recyclable plastics with recycled PET showing a drop of up to 90% in CO_2 emissions compared to virgin material (8). One disadvantage of using PET is that it can degrade when exposed to UV light for extended amounts of time which may be an issue if the heat gun was used outdoors.

Another beneficial change would be using low alloy steel for the screws instead of low carbon steel. An increased alloy metal content results in a harder material, reducing the likelihood of the heads stripping when being disassembled. This would allow for improved repairability and ease of end-of-life recycling. Low alloy steel was found to be a suitable replacement due to its increased Vickers hardness value of 215-515 HV compared to 113-168 HV of low carbon steel. The price is almost identical for both metals resulting it low alloy steel being an optimal alternative material.

Conclusion

In conclusion, the reverse engineering of the Homidic Mini Heat Gun has provided valuable insights into its design, operation, material composition and manufacturing process. The analysis revealed that the heat gun utilizes a combination of high thermal resistance polymers for insulation and stainless steel for critical components like the nozzle, ensuring durability and safety during operation. The choice of materials like low carbon steel for screws, although cost-effective, was identified as a potential weakness due to the risk of head stripping under stress, therefore it is recommended to consider a low alloy steel for these components to enhance overall durability without significantly increasing costs. It was shown that the ABS outer casing is one of the largest contributors to the carbon footprint of the product and so it is recommended to replace this with PET instead due to its similar material properties but improved sustainability.

By replacing ABS with PET for the outer casing and using low alloy steel instead of low carbon steel for the screws, the overall embodied energy of the heat gun would decrease 5% from 27.7 MJ to 26.3 MJ, whilst maintaining the same performance characteristics as the existing product. The overall CO_2 footprint would decrease 4% from 1.42 kg to 1.36 kg. In just the materials, the decrease in embodied energy and CO_2 footprint would be 8.7% and 9.1% respectively. The overall end of life potential would increase due to the improved ability to efficiently disassemble the product and separate its components. The estimated change in price between the original heat gun and that but using the replacement materials is approximately -£0.052 per unit. This means that the alternative materials selecting would not only increase the sustainability and ease of disassembly but would decrease the manufacturing price.

References

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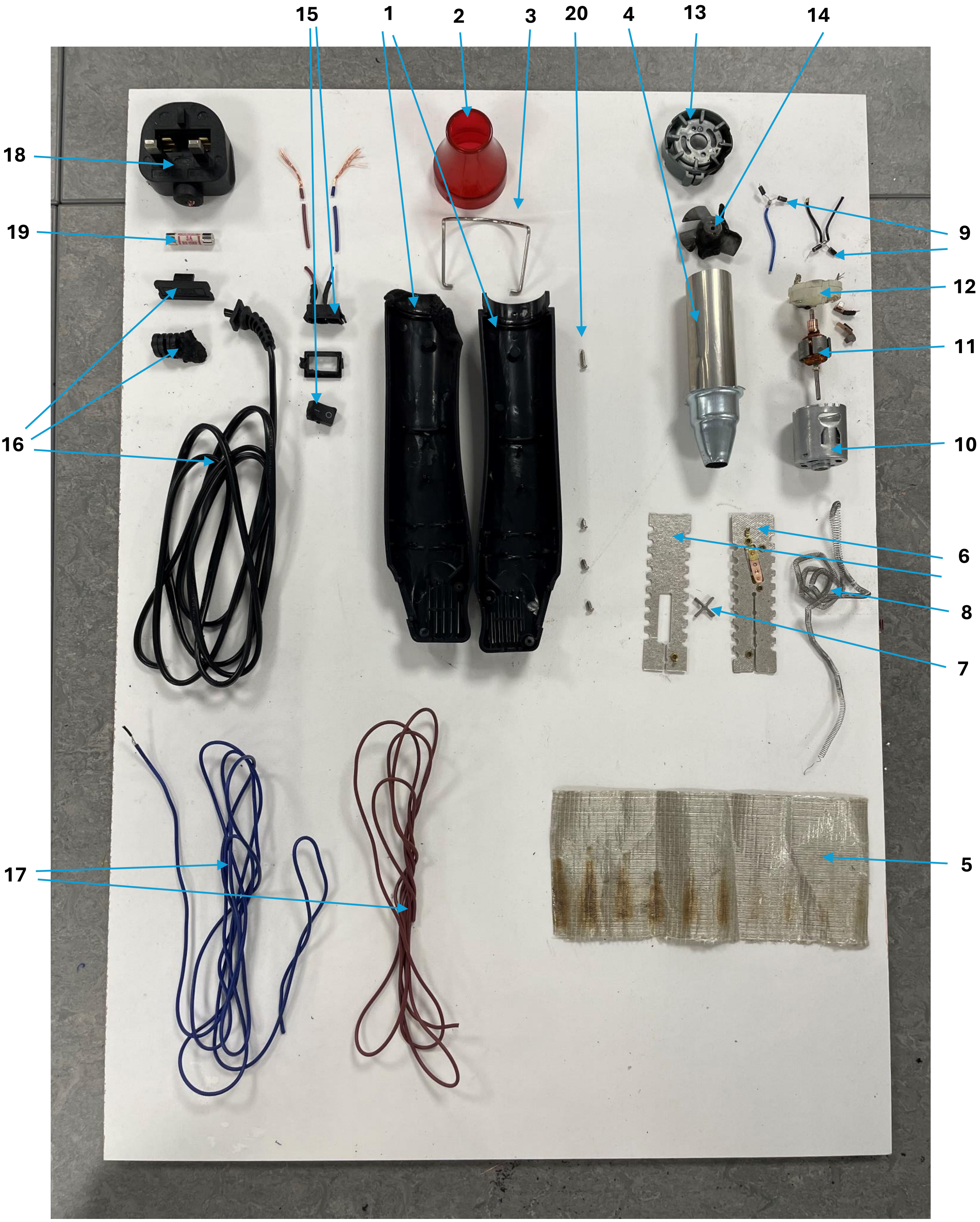
Appendices

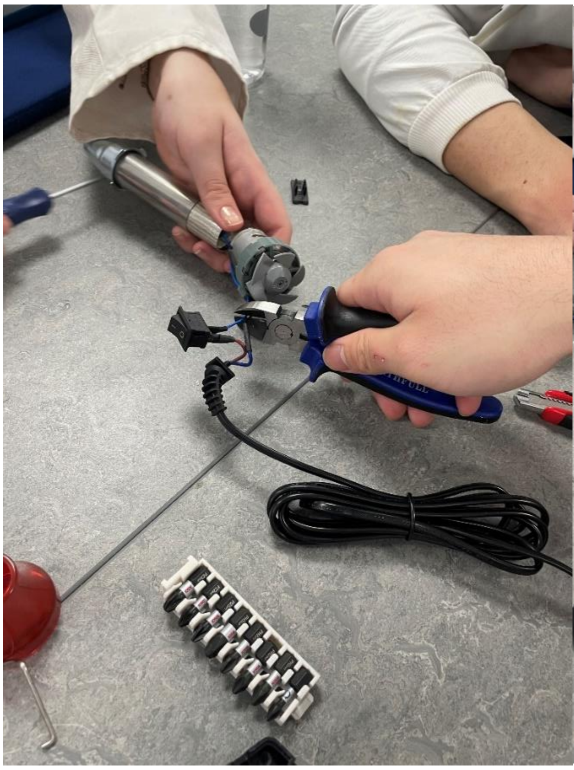
1. Annotated Full Disassembly Board



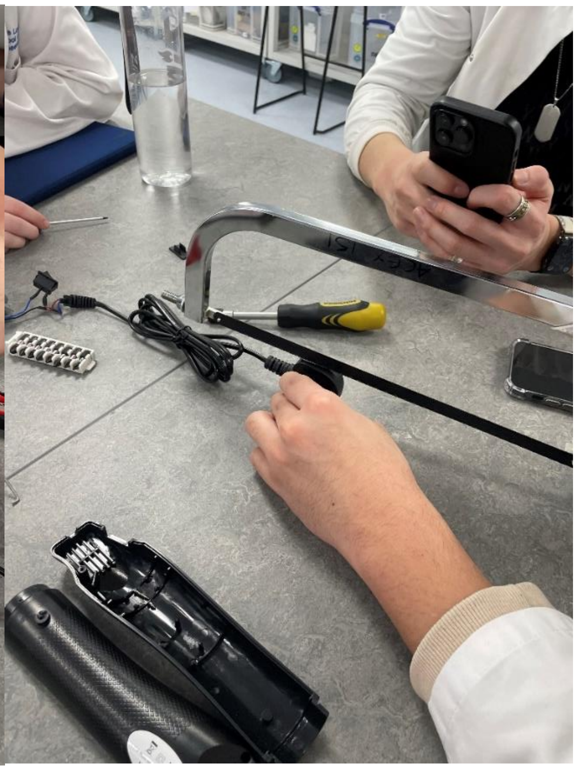
2. Disassembly Steps

a) Selecting screwdriver heads

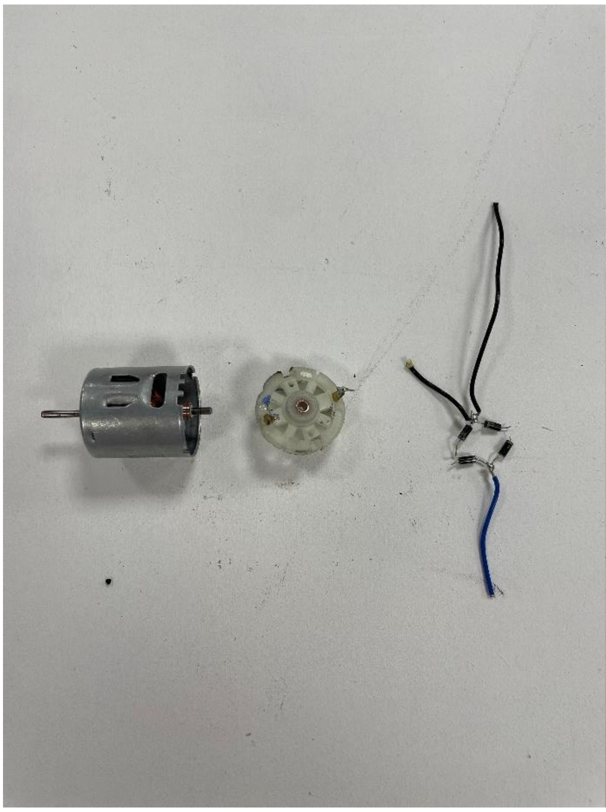
b) Outer case removal



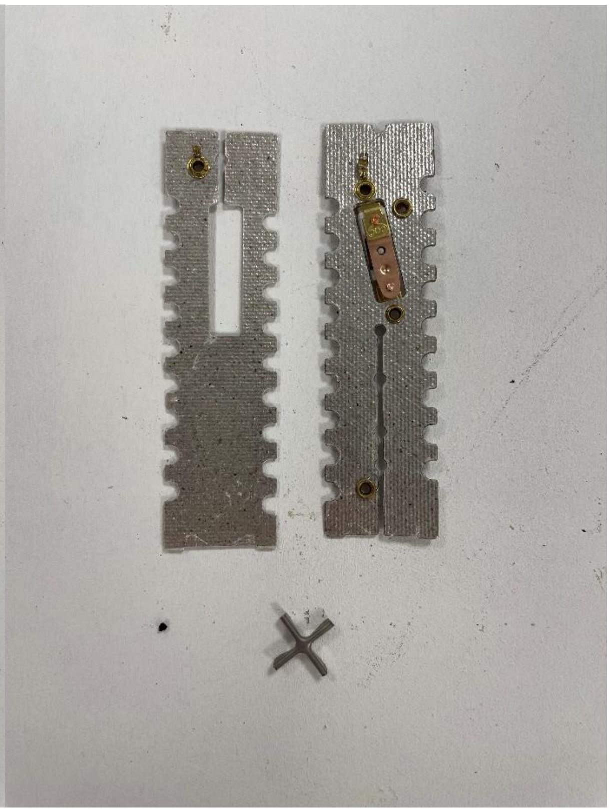
c) Removing the switch and cables



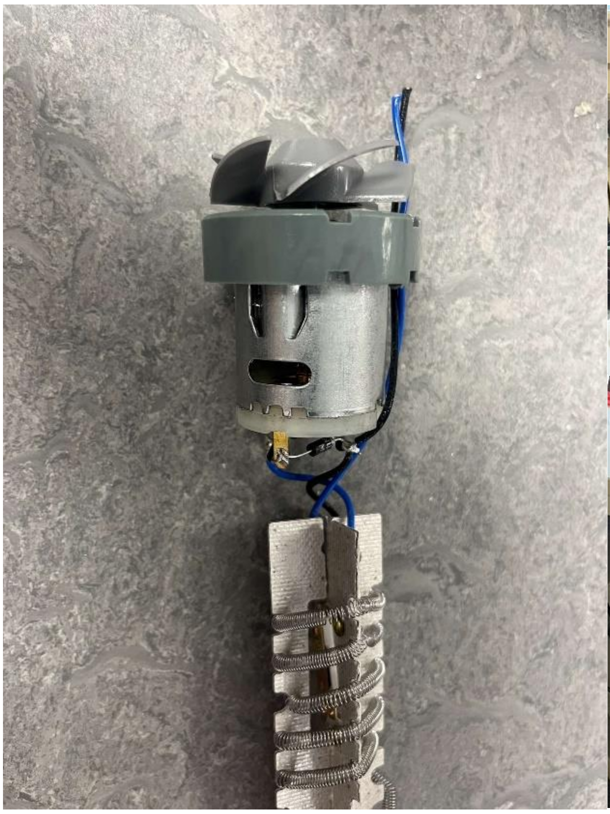
d) Cutting open the plug casing



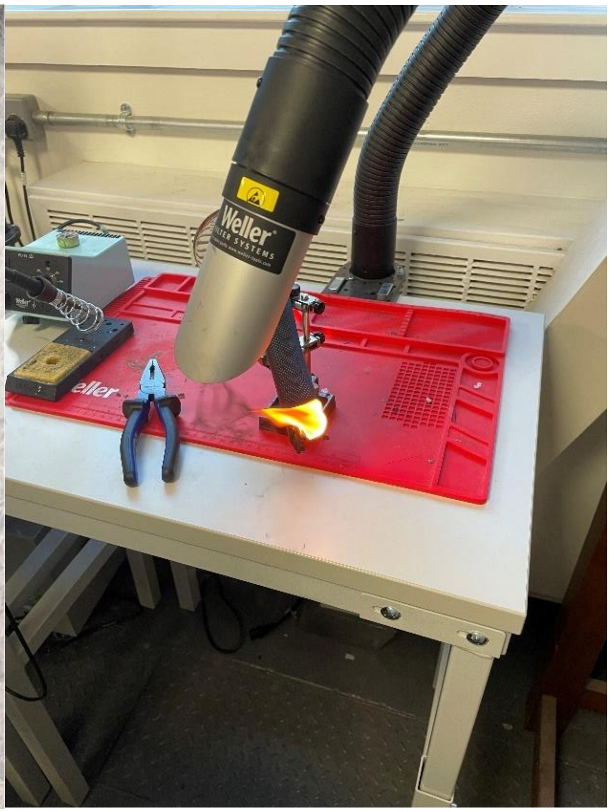
e) Disassembled motor and 4 bridge rectifier



f) Heating element support



g) Full internal assembly

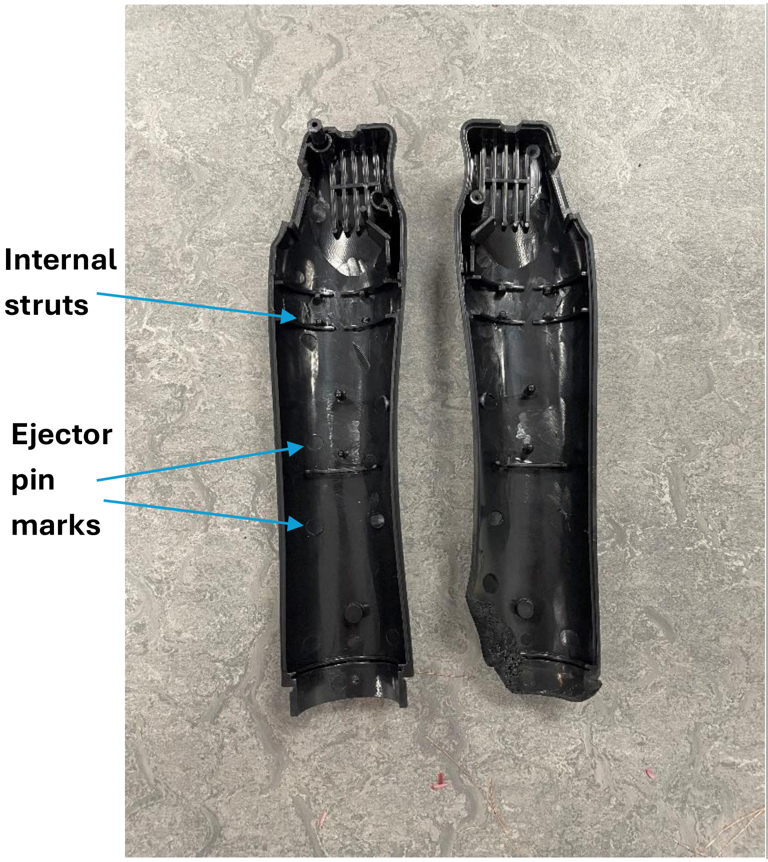


h) Polymer flame testing

3. Full Bill of Materials

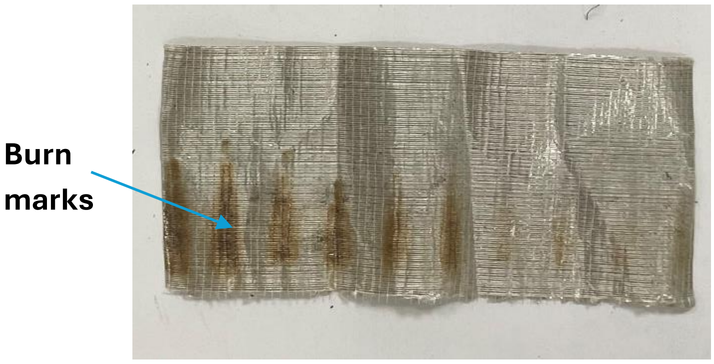
Part No	Part Name	Quantity	Primary Material	Primary Manufacturing Process	Mass per unit / g	Material Embodied Energy / MJ	Material CO2 footprint / kg
1	Outer Casing	1	ABS (C)	Injection Moulding (C)	64	4.3	0.18
2	Nozzle	1	Polycarbonate (E)	Injection Moulding (E)	10	1.2	0.059
3	Stand	1	Mild Steel (E)	Extrusion Moulding (E)	4	0.085	0.0065
4	Filament Casing	1	Stainless Steel (C)	Roll Forming (C)	28	1.4	0.11
5	Insulator	1	FRP (C)	Resin Spray-up (E)	2	0.2	0.012
6	Filament Support	1	FRP (E)	Compression Moulding (E)	8	0.81	0.048
7	Filament Divider	1	Mild Steel (E)	Stamping (E)	1	0.021	0.0016
8	Filament	1	Nickel Chromium (C)	Wire Drawing (C)	1	0.18	0.01
9	Diodes	4			< 1	2.8	0.16
10	Motor Shell	1	Mild Steel (E)	Die Casting (E)	26	0.55	0.042
11	Commutator	1	Iron (C)		14	0.14	0.011
12	Motor Top	1	PVC (E)	Injection Moulding (E)	6	0.38	0.017
13	Fan Housing	1	Polyethylene (E)	Injection Moulding (E)	4	0.32	0.0074
14	Fan	1	Polyethylene (E)	Injection Moulding (E)	2	0.16	0.0037
15	Switch	1	PVC (E)	Injection Moulding (E)	2	0.13	0.0055
16	Cable Coating	1	PVC (C)	Over moulding (C)	28	1.8	0.077
17	Wires	2	Copper (C)	Wire Drawing (C)	5	0.2	0.013
18	Plug	1	UF (C)	Injection Moulding (E)	56	4.2	0.18
19	Fuse	1			2	2.3	0.11
20	Screws	4	Low Carbon Steel (C)	Cold Rolling (C)	< 1	0.017	0.0013
Total		27				21	1.1

4. Supplementary Images



a) The internal side of the ABS outer casing

b) The compression moulded filament casing



c) The burn marks on the FRP insulator