

Reverse Engineering Project

On the Handy Stitch



Figure 1: The Handy Stitch sewing machine

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1 Technical Summary

This report covers the reverse engineering analysis of the Handy Stitch, a handheld sewing device designed for light repair applications. The product underwent a teardown to identify its constituent components, materials and manufacturing processes. A Bill of Materials was produced, and material identification was carried out using physical testing and reference data.

An environmental assessment was conducted using the Granta EduPack Eco Audit tool. The results showed that the product has an embodied energy of approximately 35.1 MJ and produces 1.98 kg of CO₂ over its life cycle, with the material production phase contributing the majority of the environmental impact.

Based on the findings in the analysis, a redesign was proposed for Wiggum PD, who requires a focus on improving durability and reliability. Key improvements include the use of glass fibre reinforced polyamide for the outer casing, enhanced structural design of the sewing mechanism, and the replacement of polymer gears with low alloy steel to improve wear resistance. Additional improvements were made to the electrical system and packaging to enhance reliability and reduce environmental impact.

The proposed redesign demonstrates how targeted material selection and design modifications can significantly improve product performance while maintaining functionality.

2 Introduction

Reverse engineering is the process of analysing an existing product to understand its design, materials and manufacturing processes₍₁₎. In this report, the product was disassembled and studied its individual components, allowing me to produce a bill of materials, helping to evaluate how the device functions, and to identify opportunities for improvement in the design.

The product analysed in this report is the Handy Stitch, a compact handheld sewing machine designed for quick and portable sewing tasks. The device allows users to carry out small repairs and stitching without the need for a full-sized sewing machine₍₂₎.

The aim of this project is to reverse engineer the Handy Stitch through a systematic teardown process. The materials and manufacturing processes used in the product will be identified and documented, and the embodied energy and carbon footprint will be estimated using the Granta EduPack Eco Audit₍₃₎ tool. Based on this analysis, a redesign of the product will be proposed for Wiggum PD₍₄₎, a company that focuses on producing rugged and durable products. The redesign will therefore prioritise improved durability, structural strength and reliability.

3 Background

3.1 Sewing and Handheld Sewing Machines

Sewing is a widely used method for joining fabrics using a thread and needle mechanism. Traditional sewing machines are commonly used in households and industry to produce reliable and consistent stitching. However, these machines require skill and setup time, which can make simple repairs inconvenient for casual users.

Advances in technology have led to the development of smaller and more portable sewing devices designed for quick repairs and simple household tasks. Handheld sewing machines provide a lightweight and compact alternative to traditional machines, allowing users to carry out basic stitching operations conveniently, on the go and with minimal setup.

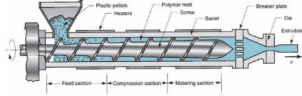
Part	Common Material & Properties	Standard Manufacturing Methods
Plastic casing ⁽⁷⁾ 	ABS (Acrylonitrile Butadiene Styrene) A tough and impact resistant thermoplastic commonly used in consumer products. It provides good strength-to-weight ratio and can be easily moulded into complex shapes.	Injection Moulding ⁽⁸⁾ 
Internal Gears ⁽⁹⁾ 	Engineering plastics Acetal (POM) or nylon are often used for small mechanical gears due to their low friction, good wear resistance and dimensional stability. These materials are cheap, lightweight, and reduce noise emitted compared to metal gears.	Injection Moulding & Milling Plastic gears are produced with injection moulding and can be further machined by milling to allow for more precise dimensional accuracy. ⁽¹⁰⁾
Needle & sewing components ⁽¹¹⁾ 	Stainless Steel Used in sewing needles and related sewing components due to its high strength, corrosion resistance and wear resistance. These properties allow the needle to repeatedly penetrate fabric without significant deformation or damage.	Machining & Wire forming Machining allows for the sharp tip and precise geometry of the needle to be created, while wire forming is suitable for slender metal components. ⁽¹²⁾
Springs & fasteners ⁽¹³⁾ 	Low carbon steel or Spring steel Used for small springs and fasteners because of its high elasticity, fatigue resistance and ability to maintain mechanical strength under repeated loading.	Cold forming & stamping Suitable for shaping small metal parts, allowing repeated production of simple fastening components with good dimensional consistency.
Electrical components ⁽¹⁴⁾ 	Copper Widely used for electrical wiring due to its excellent electrical conductivity. Polymer insulation materials such as PVC are used to protect the wiring and prevent electrical short circuits.	Wire drawing & Extrusion The copper is drawn out using wire drawing, producing the thin diameter required, before polymer insulation is then applied by extrusion.

Table 1: Typical materials and manufacturing methods used in handheld sewing machines

3.5 Design Specifications and Opportunities for Improvement

Many low-cost handheld sewing machines prioritise affordability over durability and quality, using lightweight plastics and simple designs. This reduces the overall cost, but limits the reliability and functionality. This presents opportunities for redesign, considering the philosophy of **Wiggum PD**, which prioritises durable and robust products.

4 Method

4.1 Teardown

The teardown process was carried out in a systematic manner, in order to disassemble the Handy Stitch into its smallest components. A photo of the fully disassembled product can be seen in Appendix 1 in Figure 9.

The device was first removed from its packaging. The packaging consisted of a cardboard box, plastic protective wrapping and additional accessory components including thread spools, safety pins and small sewing tools. These packaging materials were removed and set aside before examination of the main device. A photo of this can be seen in Appendix 1 in Figure 10.

The external design of the Handy Stitch sewing machine was initially inspected to understand the general layout of the product and the interaction between the user and the device. The teardown process then began by identifying the external screws in the outer casing. Using the appropriate screwdriver, they were removed. Once these screws were removed (parts 36, 37, 38), the plastic outer casing (parts 1, 2) could be separated, exposing the internal mechanical and electrical components of the sewing machine. Note that the sewing components (parts 20-35) couldn't be accessed before removing the outer casing.

Following removal of the casing, the internal layout of the device was examined. The internal components were then separated into several key functional groups, the electric motor (parts 5-16), the gear system (parts 17, 18, 41), the needle and sewing mechanism (parts 20-35, 40), and the general fastenings.

Many internal components could easily be removed by hand, with the gears and plastic components being carefully detached from their mounts. The sewing needle and metal sewing components were also removed. The electric motor was separated from the casing after disconnecting the wire connections. All components that had been soldered were cut, allowing easy removal.

During the disassembly process, care was taken to avoid damaging components to maintain the structure of the device, ensuring the function of each component could be easily understood. Each component was removed and laid out sequentially before being numbered, to allow the full assembly structure to be documented.

Once the device had been completely disassembled, all individual components were labelled and photographed. The components were then grouped according to their function and material type. The mass of individual components was measured to support later analysis of material usage, embodied energy and carbon footprint using the **Granta EduPack Eco Audit tool**.

4.2 Material and Manufacturing Identification

Following the teardown of the Handy Stitch sewing machine, several simple material identification tests were carried out in order to determine the materials used in the components of the device.

For polymer components, a plastics identification chart was used to identify the material types. The chart outlines the process of elimination used, based on flame colour, burning behaviour, odour, and other physical characteristics during heating or burning tests as well as whether the material softens when exposed to heat and whether the material floats or sinks in water. These tests allowed us to identify the polymers in the Handy Stitch. The plastics identification flowchart used in this investigation is shown in Appendix 1 in Figure 11.

Samples of every plastic component were tested with controlled heating, observing their behaviour. Observations such as the colour of the flame, the presence of smoke or soot, and the smell produced during burning were compared with the characteristics listed in the identification chart. Based on these observations, the majority of the structural plastic components were identified as ABS (Acrylonitrile Butadiene Styrene), which was expected, as mentioned in the Background section. There is a photo of the tests used in this investigation is shown in the Appendix 1 (Figure 12).

A magnet test was performed on metallic parts to determine whether they contained iron. Components that were strongly attracted to the magnet were identified as likely being steel or low-carbon steel. This largely helped identify fasteners, springs and needle sewing mechanism components.

The combination of all of these tests, as well as visual inspection allowed the materials used within the Handy Stitch to be identified with reasonable confidence. These identified materials were then used in the subsequent material analysis and Eco Audit calculations carried out using the Granta EduPack software.

To identify the manufacturing processes, visual inspections were carried out. Many of the polymer components, particularly the outer casing and internal parts, were clearly injection moulded. The signs pointing to injection moulding include parting lines, ejector pin marks and sprue scars where the polymer had entered the mould.

Metallic components were also examined with visual inspections. Features such as uniform cylindrical shapes, smooth surfaces and consistent dimensions indicated that several metal components, including the needle and shafts, were produced using machining and wire forming processes. Springs displayed tightly wound coils with uniform spacing, suggesting that they were manufactured through spring forming processes from spring steel wire. These observations allowed the manufacturing processes used in the device to be inferred with reasonable confidence.

5 Technical Discussion

5.1 Bill of Materials

A detailed bill of materials for the Handy Stitch was produced following the teardown process and is provided in the Appendix (Figure 13), the key materials can be seen below in figure 14. The table identifies each individual component of the device along with its material, manufacturing method, quantity and estimated mass.

Part Number	Part Name	Quantity/unit	Mass g	Mass per unit	Material	Method of Manufacture
1	Outer shell 1	1	34		ABS (C)	Injection moulding + milling (C)
2	Outer Shell 2	1	38		ABS (C)	Injection moulding + milling (C)
3	Battery lid	1	4		ABS (C)	Injection moulded (C)
16	MOTOR	1	40		Various	Pre manufactured part
17	Long gear	1	4		Acetal (EE)	Injection moulded (C)
18	Stubby gear	1	4		Acetal (EE)	Injection moulded (C)
19	Needle arm cover	1	4		ABS (C)	Injection moulded (C)
20	Needle arm	1	22		Stainless steel	Die cutting (C)
21	Fastening Base	1	10		Stainless steel	Die cutting (C)
22	Sewing base	1	26		Stainless steel	Die cutting (C)
40	bobbin thread	9	1.3		Polyester thread	Injection moulding + spinning (EE)
41	Rotary wheel	1	2		ABS (C)	Injection moulded (C)
46	shear blades	2	1		Stainless steel	Die cutting (C)
48	measuring tape	1	6		Polycarbonate	Paper covered in plastic (C)
52	Packaging cardboard box	1	48		Cardboard (C)	Die cutting (C)

Figure 14: Key components: Bill of Materials

It should be noted that some materials/manufacturing methods may not be accurate as a few guesses were made, but the overall outcome should be a good approximation. It should be noted the result may not be accurate as a few guess and estimation were used but is a good approximation. In the columns of Material and Methods of Manufacture, a confidence scale has been implemented, with G (guess), EE (educated estimation) and C (confirmed).

Furthermore, the motor was modelled as a combination of materials within the EcoAudit tool to improve the accuracy of the analysis₍₁₈₎. Rather than treating the motor as a single component, it was broken down into representative material groups including steel, copper, polymer and ferrite.

Due to limitations within the Level 2 database, certain materials were approximated. Ferrite components were modelled using alumina, and carbon-based elements were approximated as steel to ensure compatibility with available material data. While these substitutions introduce minor inaccuracies, they provide a reasonable estimation of the motor's material composition for the purposes of embodied energy and CO₂ analysis.

This approach ensures that the relative contribution of high-impact materials, such as copper and steel, is captured more accurately than if the motor were treated as a single homogeneous component. The full Bill of Materials used within the Eco Audit can be found in the Appendices.

In total, the product was found to consist of 55 individual components, including structural parts, mechanical components, electrical elements and packaging materials. The majority of these parts are fasteners and connectors that contribute minimally to the total mass but are essential to the assembly and function of the product.

The product is primarily composed of two main material groups: polymers and stainless steel. Polymer materials such as ABS, acetal and polyethylene are used extensively in the outer casing, gears and auxiliary components due to their low cost, low weight and ease of manufacturing through injection moulding. Stainless steel is used for critical structural and functional components such as the needle arm, sewing base, springs and fasteners because of its high strength, corrosion resistance and durability under repeated mechanical loading.

The heaviest individual components identified include the electric motor (approximately 40 g), the outer casing halves (34 g and 38 g respectively), the sewing base (26 g) and the packaging cardboard box (48 g). These components therefore represent the largest contributors to the overall mass of the product.

The bill of materials also highlights that the product has been designed with a strong emphasis on low-cost manufacturing and high-volume production. Many components are produced using injection moulding or simple metal forming processes, while several small parts such as the motor are standard pre-manufactured components integrated into the assembly. This design strategy reduces manufacturing complexity and production cost while maintaining the required functionality of the device.

The material composition and component distribution identified in the bill of materials also provide the basis for the subsequent material, manufacturing and environmental analyses.

5.2 Material Analysis

All data in the following discussion were extracted from **CES EduPack 2022** unless otherwise specified.

5.2.1 Polymers

Acrylonitrile butadiene styrene (ABS)

ABS (Acrylonitrile-butadiene-styrene) is tough (Young's Modulus of 2.07 - 2.76 GPa), resilient, and easily moulded. It is usually opaque, although some grades can now be transparent, and it can be given vivid colours, as it takes colour well. ABS-PVC alloys are tougher than standard ABS and, in self-extinguishing grades, are used for the casings of power tools.

ABS has the highest impact resistance of all polymers (Vicker's Hardness of 10 – 15 HV). ABS is UV resistant for outdoor application if stabilizers are added. It has good chemical and temperature resistance. It can be extruded, compression moulded or formed to sheet that is then vacuum thermoformed. It can be joined by ultrasonic or hot-plate welding, or bonded.

ABS is popular within the industry, and used on the Handy Stitch mostly in the Outer Casing, as well as small interior components. It is also cost-effective (1.27 - 1.85 GBP/Kg), fitting the original design criteria.

Polyurethane (tpPUR)

Polyurethane is often related to soft, stretchy materials and fabrics (Lycra or Spandex), but they can also be leathery or rigid (Young's Modulus of 1.31 - 2.07 GPa). Polyurethanes have thermoplastic, elastomeric and thermosetting grades. They are easily foamed; some 40% of all PU is made into foam by mixing it with a blowing agent. PU is a versatile material.

PU foams are cheap (2.24 - 2.49 GBP/Kg), easy to shape (Mouldability score of 3 - 4), and have good structural performance, making it a good choice for the small internal components in the Handy Stitch.

Polycarbonate (PC)

PC is one of the 'engineering' thermoplastics, meaning that they have better mechanical properties than the cheaper 'commodity' polymers (PC has a Young's Modulus of 2.32 - 2.44 GPa, Vicker's Hardness test of 18 – 20 HV and Yield Strength of 59.1 - 65.2 MPa). PC has unique characteristics of optical transparency (Refractive Index of 1.58 - 1.59) and good toughness and rigidity, even at relatively high temperatures.

The processing of engineering thermoplastics requires a higher energy input than that of commodity plastics, but remains at a similar price to tpPUR (1.85 - 2.37 GBP/Kg).

Polycarbonate is largely used for the battery holder and small components in the Handy Stitch.

Cellulose polymers (CA)

Cellulose is one of the main structural polymers in plants, which when treated with acid produces a resin. Cellulose Acetate is the most common Cellulose material. CA combines toughness (Fracture toughness of $1.5 - 1.8 \text{ MPa} \cdot \text{m}^{\frac{1}{2}}$), transparency (1.47 - 1.48 Refractive index) and a natural surface texture. Some cellulose resins are biodegradable. They have glossy surfaces and a self-polishing effect that allows surface scratches to disappear with use.

It has excellent flow properties and so is well-suited to injection moulding but the resin must be kept dry.

In the Handy Stitch CA is used on the switches on the exterior, where aesthetic and ergonomics are prioritised.

Polyvinylchloride (tpPVC)

PVC - Vinyl - is one of the cheapest (1.32 - 1.44 GBP/Kg), most versatile and - with polyethylene - the most widely used of polymers and epitomizes their multi-faceted character. In its pure form - as a thermoplastic, tpPVC - it is rigid, and not very tough (Young's Modulus of 2.2 - 3.1 GPa and Yield Strength of 37.6 - 45.5 MPa); its low price makes it a cost-effective engineering plastic where extremes of service are not encountered. Incorporating plasticizers creates flexible PVC.

PVC is used in the Handy Stitch largely as wire coatings in its flexible form.

Polyoxymethylene (Acetal, POM)

POM is similar to nylon but stiffer (2.6 - 3.2 GPa Young's Modulus), and has better fatigue (Fatigue strength at 10^7 cycles 22 – 26 MPa) and water resistance - nylons, however, have better impact and abrasion resistance. It is rarely used without modifications: most often filled with glass fibre, flame retardant additives or blended with PTFE or PU. The last, POM/PU blend, has good toughness. POM is used where requirements for mouldability, fatigue resistance and stiffness combined with its low price (0.976 - 1.13 GBP/Kg) are required.

Acetal is used in the Handy Stitch for the gears and smaller internal components.

5.2.2 Metals

Stainless Steel

Stainless steels are alloys of iron with chromium, nickel, and - often - four or five other elements. Most stainless steels resist corrosion in most normal environments, and they remain ductile to the lowest of temperatures.

Stainless steel must be used efficiently to justify its higher costs (2.12 - 2.27 GBP/Kg), exploiting its high strength (Young's Modulus of 190 – 210 GPa) and corrosion resistance. Economic design uses thin, rolled gauge, simple sections.

Stainless Steel is used on the Handy Stitch on the exposed sewing mechanisms as well as parts of the internal mechanisms.

Copper

Copper is heavy (its density is $8.94 \times 10^3 \text{ Kg/m}^3$) and soft (Vicker's Hardness of 46.3 - 115 HV), not what you want for good mechanical performance. It is in its thermal, electrical, environmental and aesthetic qualities that copper excels. Its thermal and electrical conductivities are greater than those of any other metal except silver, and it is 50 times more expensive (4.42 - 4.47 GBP/Kg). It is exceptionally durable (Fatigue strength at 10^7 cycles is 70.6 - 115 MPa) and it is visually attractive.

Copper is easy to draw into a wire, and used for the wires in the Handy Stitch.

Low Carbon Steel

Low carbon steel is strong (Young's Modulus of 200 - 220 GPa), tough, easily formed (Formability scale is 4 - 5) and cheap (0.524 - 0.552 GBP/Kg). Carbon steels are alloys of iron with carbon and, often a little manganese, nickel, and silicon. They are relatively soft and are the cheapest of all structural metals.

The production energy of steel is comparatively low - per unit weight and easy to recycle.

Please note this was used to model Graphite (within the motor) in the Eco Audit due to no option in Level 2 database.

5.2.3 Other Materials

Ceramic - Alumina

Alumina (Al_2O_3) is cheap (13.7 - 20.6 GBP/Kg), easy to process, the workhorse of the industry, often used for its wear and high temperature resistance (Maximum service temperature of $1.44 \times 10^3 - 1.51 \times 10^3 \text{ }^\circ\text{C}$).

Alumina was used to model ferrite within the motor of the Handy Stitch as there was no option on the Level 2 database. This may cause a slight overestimation of the environmental impact, but is still useful as an approximation.

Paper and Cardboard

Paper is made from pulped cellulose fibres derived from wood, cotton or flax. There are many different types, but it is used for packaging for the Handy Stitch. It is very lightweight ($700 - 1.15 \times 10^3 \text{ Kg/m}^3$), low cost (0.743 - 0.909 GBP/Kg) and cardboard is structurally rigid.

5.3 Manufacturing Analysis

All data in the following discussion were extracted from **CES EduPack 2022** unless otherwise specified.

5.3.1 Polymer Manufacturing Methods

Injection Moulding

The Handy Stitch's polymer components are largely injection moulded, for example the outer casing. This could easily be deduced from the sprue scars and ejector pin marks on the inside.

Injection moulding of thermoplastics is the equivalent of pressure die casting of metals. Molten polymer is injected under high pressure into a cold steel mould. The polymer solidifies under pressure and the moulding is then ejected. Various types of injection moulding machines exist, but the most common in use today is the reciprocating screw machine (shown schematically).

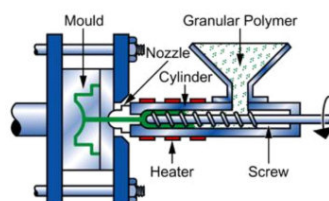


Figure 15: Injection Moulding Schematic

Capital and tooling costs are very high (Relative cost index of 11.9 - 35.5 GBP per unit, with capital costs and tooling costs $2.46 \times 10^4 - 5.54 \times 10^5 \text{ GBP}$ and $2.46 \times 10^3 - 2.36 \times 10^4 \text{ GBP}$ respectively). Production rate can be high particularly for small mouldings. The process is used almost exclusively for large volume production (Economic batch size of $1 \times 10^4 - 1 \times 10^6$ units). Quality can be high but may be traded off against production rate. Complex shapes are possible, though some features (e.g. undercuts, screw threads, inserts) may result in increased tooling costs.

Polymer Extrusion

In polymer extrusion, polymer in powder or granule/pellet form is processed by a rotating screw through a heating chamber and the resulting melt is forced through a shaped die orifice.

The extrudate is cooled as it leaves the die. The extrudate is then 'drawn down' to a smaller cross-section. Variations of the process include film blowing, extrusion blow molding and filament forming.

The process is used to coat wire (used in the Handy Stitch), which can be achieved at very high speeds. Extrusion is also used as a preprocess to many of the molding processes such as injection molding.

Die design is complicated by 'die swell', hence tolerances are not as tight as for the pressure moulding processes (0.5 - 1 mm).

Limited to uniform prismatic shapes (constant cross-section). Fairly complex cross-sections are possible including hollow shapes. Tooling cost range (1.01×10^3 - 5.04×10^3 GBP and relative cost index 8.64 - 13.8 GBP per unit) covers small and simple to large and complex dies, which remains fairly low, although capital costs are fairly high and output usually requires further processing.

5.3.2 Metal Manufacturing Methods

Sheet Forming

Many products are made by cutting, pressing, punching, folding or spinning of sheet. The Handy Stitch uses die cutting for smaller metal components and parts of the sewing mechanism.

Press forming covers a range of sheet forming processes that use a die and a press. Tooling costs are high (19.6 - 603 GBP per unit), due to the number of tools required. High production rates, tooling and capital costs make the process economic only for large production levels.

5.3.3 Both Polymer and Metal Manufacturing Methods

Forging

Forging produces components with particularly good mechanical properties but dies for forging have to be made from exceptionally hard materials and are expensive (Forging relative unit cost 12.4 - 24.2 GBP), meaning that shape rolling and closed die forging are suitable only for large batches (Economic batch size 1×10^3 - 1×10^5 units).

In forging a metal ingot is squeezed to shape by dies that subject it to large plastic deformation. In hot die forging a heated blank is formed between open or closed dies in a single compressive stroke. Often a succession of dies is used to create the final shape. In cold rolling and forging the metal blank is initially cold, although deformation causes some heating. The greatest precision and shape complexity is given by closed-die forging, illustrated below (Figure 16), but the size of component is limited to about 20 kg. Open-die forging is less precise, but can be applied to much larger components (up to 5000 kg).

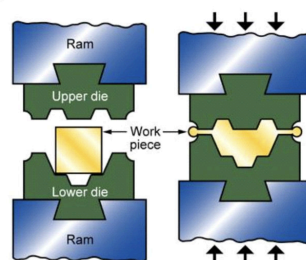


Figure 16: Forging Schematic

Milling

In milling, metal or polymer is removed by a rotating multiple-tooth cutter; each tooth removes a small amount of metal with each revolution of the spindle. Because both workpiece and cutter can be moved in more than one direction at the same time, surfaces having almost any orientation can be machined.

All polymers and all but the hardest metals can be machined by milling. Ceramics and glasses can be drilled and cut, but require diamond or carbide-tipped tools. Very intricate shapes, high precision and finish are possible, but at a cost, as well as a range of batch sizes (1 - 1×10^7 units).

The Handy Stitch uses milling for both large polymers (Outer Shell) as well as a few steel parts that are used in the sewing mechanism.

5.4 Embodied Energy and CO₂ Footprint

Embodied energy (EE) refers to the total energy required to extract raw materials, process them into usable forms, manufacture components and transport the final product to the point of use₍₁₆₎. The carbon footprint represents the quantity of CO₂ emissions generated during these processes₍₁₇₎. These metrics are widely used as sustainability indicators for evaluating the environmental impact of engineered products.

To estimate the embodied energy and CO₂ footprint of the life-cycle of the Handy Stitch, the Eco Audit tool in the Granta EduPack was used. The bill of material produced were analysed and entered into the Eco Audit tool using Level 2 of the database. As mentioned in the Material Analysis section, where any material was unavailable (Graphite and Ferrite), an assumption was made and they were modelled as a material as close to it as possible.

For the transport section, the product was assumed to be manufactured in China and then shipped overseas to the United Kingdom. The first leg consisted of approximately 200 km of road transport via truck from the facility to the port. The product then travelled approximately 20,000 km by sea freight to the UK. Next, the product was transported 300 km by a heavy goods vehicle to a distribution centre before a final 50 km to the user via delivery van.

The use phase assumed the product had a lifespan of approximately five years, based on reviews and product descriptions. This also reflects the low-cost, handheld sewing machine which is only designed for occasional repairs. The motor within the device is approximately 10 W, which matches with the small DC motor inside. Finally, it was assumed the product would be used roughly one hour a week.

The Eco Audit results indicate that the Handy Stitch has a total embodied energy of approximately 35.1 MJ and produces an estimated 1.98 kg of CO₂ emissions over its first life cycle. The results show that the material production phase dominates the environmental impact, contributing approximately 80.4% of the total embodied energy and 73.8% of the total CO₂ emissions. The overall table can be seen below in Figure 17.

Phase	Energy (MJ)	Energy (%)	CO2 footprint (kg)	CO2 footprint (%)
Material	28.2	80.4	1.46	73.8
Manufacture	5.2	14.8	0.397	20.1
Transport	1.62	4.6	0.117	5.9
Use	0	0.0	0	0.0
Disposal	0.0776	0.2	0.00543	0.3
Total (for first life)	35.1	100	1.98	100
End of life potential	0		0	

Figure 17: Eco Audit Summary Table

The material phase contributes highly due to injection moulded polymer parts as well as the stainless steel components. The outer ABS casing, acetal gears and stainless steel mechanisms account for the majority of the mass and therefore the most of the embodied energy. Although injection moulding isn't that energy intensive, the polymers used have to be created as none of it is recycled, requiring significant energy during production.

The manufacturing processes make up approximately 14.8% of the embodied energy and 20.1% of the total CO₂ emissions. This is due to processes such as injection moulding, metal stamping, machining and wire forming being used to produce components. On a large batch scale, manufacturing emissions and embodied energy will be fairly low, especially compared with the raw material production for each product.

The transport section of the life-cycle contributes approximately 4.6% of the total embodied energy and 5.9% of the CO₂ footprint. Despite the product travelling over a large international shipping distance, the relatively small mass of the device limits the environmental impact in regards with transportation.

Finally, the use phase contributes negligible energy consumption and CO₂ emissions due to the low power requirement of the small DC motor and the limited use of the product. Disposal also represents a very small portion of the overall environmental impact, due to the tiny size of the product.

Overall, the EcoAudit reveals the environmental impact of the Handy Stitch largely comes from the materials used. This suggests that any steps to reduce the embodied energy and carbon footprint would be focused on the quantity and selection of materials for the product. This is critical for considering potential design improvements in the redesigned product.

6 Reverse Engineering Solutions

6.1 Material Considerations

6.1.1 Outer Case Redesign

The Handy Stitch was originally made from ABS using injection moulding. Although this allowed for functions such as internal ribs, screw bosses and an ergonomic geometry, it only provided moderate mechanical performance, particularly in terms of fracture toughness and resistance to impact. As this product is being redesigned for Wiggum PD, durability and resistance to harsh handling are primary priorities, therefore ABS is not suitable.

The redesign focuses on improved durability, with resistance to impact, crack propagation and initiation prioritised. Secondary considerations such as cost and large-scale manufacturability were not prioritised, as Wiggum PD emphasises robustness over economic constraints.

A systematic material selection process was carried out using the Level 2 database in Granta EduPack. Prior to this, a user perception study was conducted to understand the desired tactile and ergonomic properties of a handheld sewing device (See Appendix 3 for full figures and links). The results indicated a strong preference for materials that feel warm, grippy, lightweight and comfortable to hold. These characteristics are typically associated with polymer-based materials rather than metals, which are often perceived as cold, rigid and heavier in use.

Based on these findings, all material classes were initially considered and then filtered accordingly. Ceramic materials were excluded due to their low fracture toughness and brittle failure behaviour, making them prone to fracture under impact. Metals were also considered; however, despite their high strength, their higher density and less favourable tactile properties made them less suitable for a handheld, user-interactive device.

This narrowed the selection to engineering polymers and composite materials. An Ashby chart of fracture toughness against density was generated, as shown in Figure 18 (See Appendix 4). Fracture toughness was selected as the key performance index, as it directly represents a material's resistance to crack propagation under impact, which is critical for durability in the Wiggum PD application. Density was included to ensure that improvements in durability would not significantly increase the weight of the device.

A performance index was not explicitly applied, as fracture toughness does not apply to a simple linear optimisation in this context. Instead, materials were selected based on maximising fracture toughness while maintaining low density.

As shown above, ABS lies fairly low in regards to fracture toughness compared with fibre-reinforced composites. This indicates composites have improved resistance to crack propagation and impact failure. Although carbon fibre reinforced polymers exhibit high performance, their relatively brittle failure behaviour makes them less suitable for applications prone to impact forces.

Glass fibre reinforced polymers, on the other hand, provide both fracture toughness and the desired density. The chart shows that GFRP achieves a much higher toughness than ABS, while moderately increasing density. This indicates that substantial improvements in durability can be achieved without compromising the lightweight nature of the handheld device.

Therefore, glass fibre reinforced polyamide (GFRP) was selected as the most suitable material for the redesigned outer casing. This material offers enhanced resistance to impact, improved structural integrity and better performance under repeated loading, making it well suited to the durability requirements of the Wiggum PD application. See Appendix 5 (Figure 34) for rendered Outer Case.

6.1.2 Sewing Mechanism Redesign

An Ashby plot was created with durability in mind, plotting yield strength against durability, as seen in Appendix 4 in Figure 19. The results indicate that stainless steel already lies within the upper region of performance for this application, providing a favourable balance of strength and density compared to alternative materials.

This suggests that the original material choice is appropriate for the sewing mechanism. Therefore, further improvements in durability are better achieved through design and manufacturing modifications rather than replacing the base material.

6.1.3 Internal Gears Redesign

The internal gear system in the Handy Stitch is responsible for connecting the motor to the sewing mechanism. In the original design, the gears were made from acetal (POM), which is used due to its low friction, and adequate wear resistance, combined with low cost, makes it suitable for light applications.

However, designing the product for Wiggum PD, the durability must be increased under repeated loading. In this case, resistance to wear is a priority, as the gear teeth will be continually sliding and under stress during operation.

An Ashby chart was created of hardness against density, as shown in Figure 20 in Appendix 4. The hardness was selected as it is the closest to surface wear offered by Granta EduPack, providing a useful indicator. Density is retained on the second axis to ensure the improvements in durability are not at the expense of the product being handheld and lightweight.

A simple performance index was considered, with density linearly proportional to density, favouring materials that maintained a low mass and improved surface durability over acetal.

As shown in Figure 20 above, acetal (POM), used in the original design, lies within a relatively low hardness region compared to alternative materials. Reinforced polymers offer some improvement; however, metals occupy a substantially higher hardness region and are therefore better suited to repeated contact and wear-dominated applications such as gear transmission.

Low alloy steel provides the highest hardness value, indicating improved resistance to surface wear and deformation.

Therefore, low alloy steel was selected as the most suitable material for the redesigned internal gear system. This material provides improved resistance to wear, tooth deformation and long-term mechanical degradation, making it more appropriate for the durability-focused requirements of the Wiggum PD application.

6.1.4 Switch/Electrical Redesign

The electrical system in the Handy Stitch uses a small DC motor powered by batteries and controlled using a sliding switch mechanism. Conductive materials such as copper alloys provide efficient electrical performance, while polymer components offer electrical insulation and user safety.

Therefore, no significant material changes are required for the electrical system, as the existing materials already meet the functional requirements of the device.

6.2 Manufacturing Considerations

6.2.1 Outer Case Redesign

The selected material for the outer case, GFRP, can still be injection moulded, allowing for the complex geometries required for the internal features within the Handy Stitch. This ensures that the improved material performance does not compromise manufacturability.

However, to further enhance durability, design modifications are proposed alongside the material change. These include increased wall thickness in high-stress regions, the addition of reinforcing ribs, and improved load distribution around screw bosses and fastening points.

Additionally, overmoulding techniques could be applied to introduce a secondary elastomer layer in key contact regions. This would improve impact resistance and provide enhanced grip, further supporting the durability requirements of the Wiggum PD application.

6.2.2 Sewing Mechanism Redesign

As the material study indicated that stainless steel already meets the functional requirements of the sewing mechanism for Wiggum PD, improvements to the durability can be achieved through design modifications.

The redesigned mechanism increases thickness in load-bearing components, especially the needle arm and connections. This reduced the risk of bending and permanent deformation under repeated use cycles. Furthermore, improved support and aligned moving parts can be introduced to minimise side-to-side movement and stress concentrations, ensuring efficient force transmission.

The stainless steel can also be further hardened to improve wear resistance without affecting the overall geometry or mass of the components.

Collectively, these modifications improve the reliability and lifespan of the sewing mechanism, making it more suitable for the durability-focused requirements of the Wiggum PD application.

6.2.3 Internal Gears Redesign

In the original design, the polymer gears are likely manufactured using injection moulding. This process is highly cost-effective and suitable for high-volume production, but it limits achievable hardness and wear resistance, which restricts the durability of the component under repeated loading.

For the redesigned system, low alloy steel gears can be produced using established metal manufacturing processes such as precision machining. This will allow for tighter tolerances and improved dimensional accuracies, which is critical for effective gearing and long-term reliability.

To further enhance durability, heat treatment processes such as quenching can be used. This increases the surface hardness of the gear teeth, significantly improving wear resistance and fatigue performance.

In addition to material changes, geometric improvements can also be implemented. Increasing the thickness or number of gear teeth reduces the likelihood of tooth failure under repeated loading, while improved surface finishing can reduce friction and wear during operation.

Although the use of low alloy steel improves the surface hardness and wear resistance, it is fairly heavy. Designing for Wiggum PD means prioritising the gain in mechanical performance, therefore this material choice is appropriate.

An additional consideration of replacing polymer gears with metallic gears is the increase in operational noise. In this application, the increase in noise is considered an acceptable trade-off given the priority placed on durability and wear resistance for the Wiggum PD design brief.

6.2.4 Switch/Electrical Redesign

The material selection remains appropriate, but the switch can be redesigned to enhance durability and reliability. The original switch used exposed contacts, which are prone to wear, contamination and inconsistent electrical connection.

Additionally, improved contact materials and tighter assembly tolerances can be used to ensure consistent electrical performance. Better integration of the switch within the casing can also provide increased structural support and reduce the likelihood of mechanical failure.

These modifications improve the reliability of the electrical system without significantly increasing complexity, aligning with the durability-focused design brief of Wiggum PD.

6.3 Packaging Redesign

The packaging of the Handy Stitch consists of a cardboard box, plastic bags, and protective cushioning materials. This provides adequate protection during transport, but it contributes to unnecessary material usage and environmental impact.

Based on the findings from the Eco Audit analysis, material usage is a significant contributor to the overall embodied energy and CO₂ footprint of the product. Therefore, the redesigned packaging aims to reduce material consumption while maintaining sufficient protection.

A new packaging system with pulp inserts and recycled cardboard reduces the environmental impact while keeping the structural integrity.

7 Conclusion

The Handy Stitch sewing machine was analysed with the Eco Audit tool, showing the total embodied energy of approximately 35.1 MJ and a CO₂ footprint of 1.98 kg over its first life cycle. The material production phase was the largest contributor to the energy consumption and emissions, 80.4% and 73.8% respectively. This is primarily due to the use of polymer components and metallic elements within the device.

Following the reverse engineering analysis, several improvements were made with a focus on durability, in line with the requests of Wiggum PD. The outer casing was redesigned to be made with glass fibre reinforced polyamide to improve impact resistance and structural strength, supported by enhanced internal ribbing and improved assembly features. The sewing mechanism retained stainless steel as the base material, with durability improvements achieved through increased component thickness, improved alignment and potential surface treatments.

The internal gear, originally made from acetal, was replaced with low alloy steel to enhance the wear resistance and long-term durability. Although this increases the weight and noise produced, these trade-offs are acceptable considering the brief. Improvements to the enclosed switch were also proposed, to improve reliability. Also, the packaging was redesigned using recycled cardboard and moulded pulp inserts to reduce the environmental impact while maintaining protection during transport.

Overall, the redesign prioritises mechanical durability, and long-term reliability, reflecting the requirements of Wiggum PD. While some trade-offs are introduced, such as increased weight, and noise from the gears, the improved performance and extended product lifespan justify these changes.

This demonstrates that targeted material selection and design modifications can significantly enhance product performance while maintaining functional requirements.

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9 Appendices

9.1 Appendix 1

Teardown Boards and Photos, and Plastics Chart

Complete Teardown Boards (Numbers all relate to Bill of Materials):

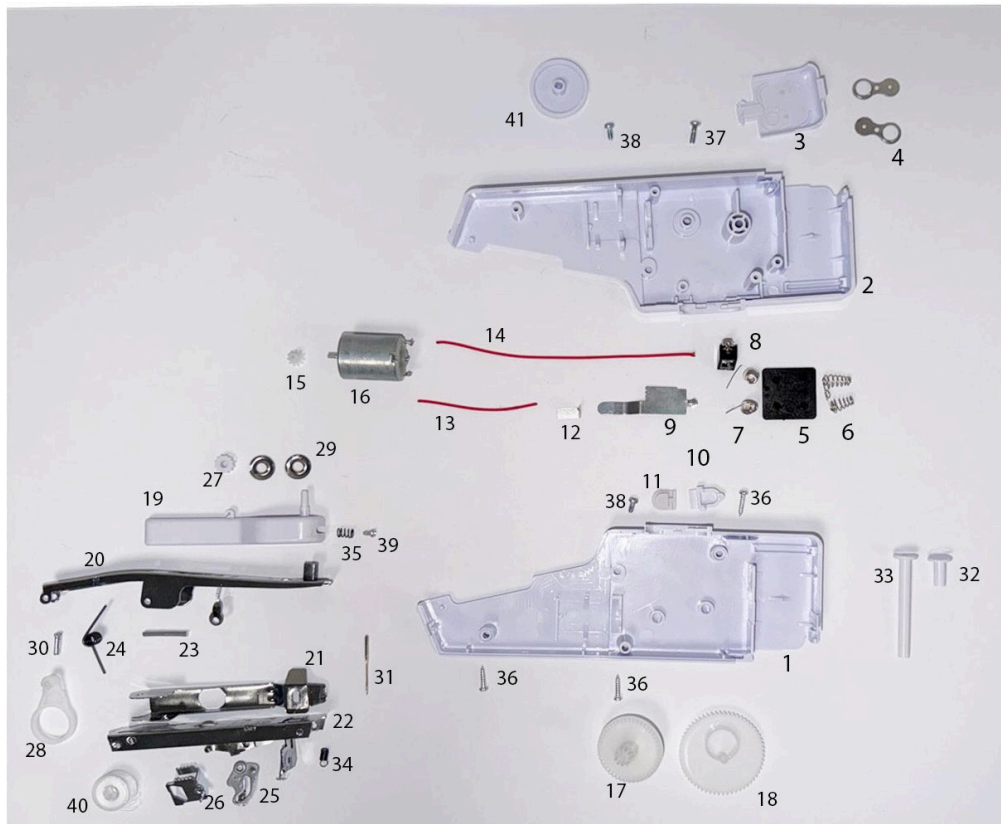


Figure 9: A display board of the teardown completed



Figure 10: A display board of all extra components + Packaging

Below are photographs of the Handy Stitch undergoing the teardown process (Figures 21–26). From left to right, the first row illustrates the progressive disassembly of the device. The first image shows the removal of the outer casing, exposing the internal components. The second image presents the removal of the switch and battery enclosure while the remaining internal components are left intact. The third image shows the process of removing the sewing mechanism from the main body.

The second row focuses on the internal components following further disassembly. The first image shows the removal of the internal gear system and motor. The second image isolates the motor assembly, and the final image presents the fully disassembled sewing mechanism.

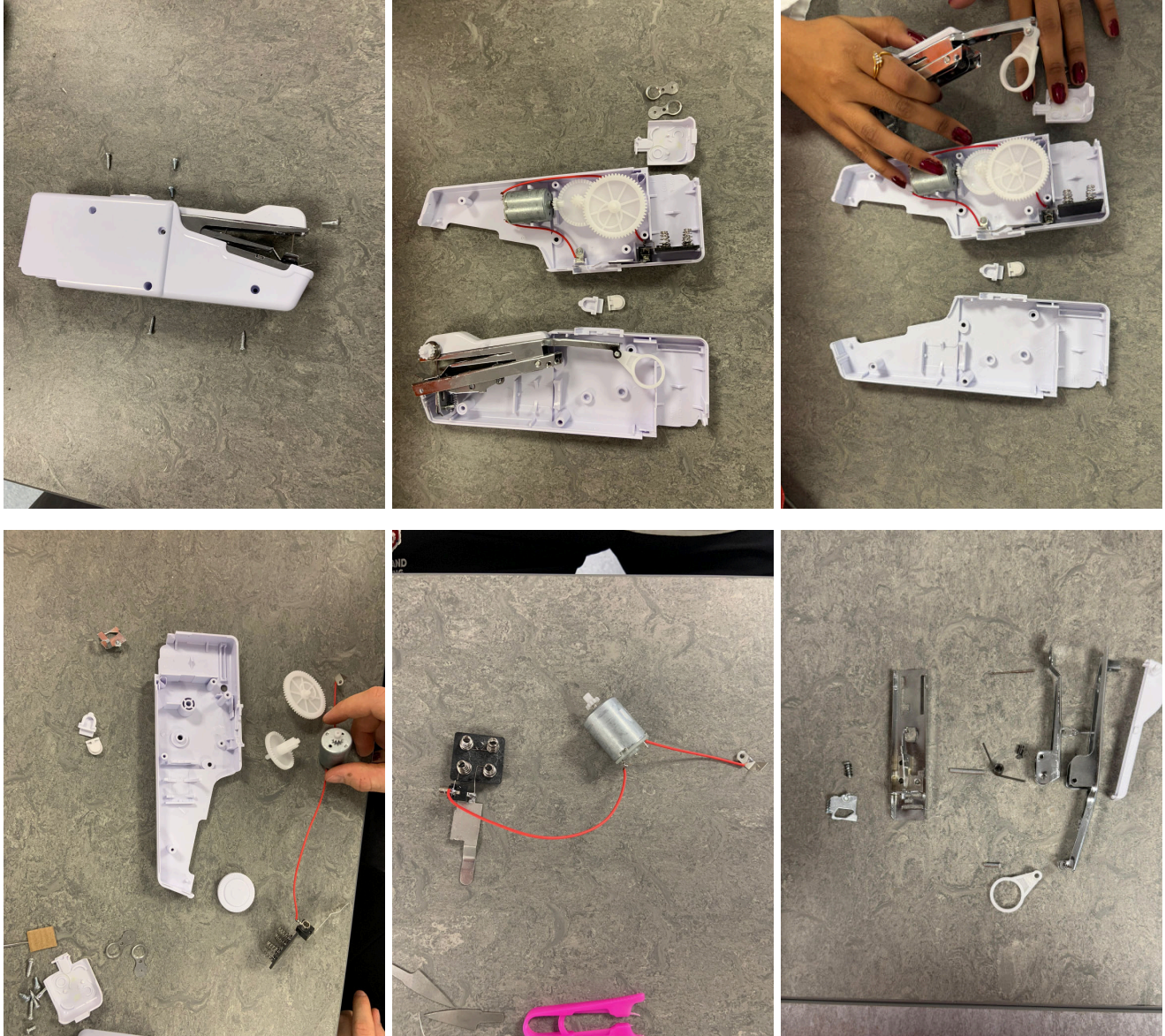


Figure 3: Teardown Process

Figure 12 below shows the material identification process carried out on a polymer component. The sample was first subjected to a density test by placing it in water, where it was observed to float, indicating a density lower than that of water.

Following this, a melt test was performed to further identify the polymer type based on its thermal behaviour. The response of the material during heating was compared against standard polymer identification charts, allowing for a more accurate classification of the material.

This combination of simple physical testing methods provided a practical and effective approach for identifying unknown polymer components within the device.

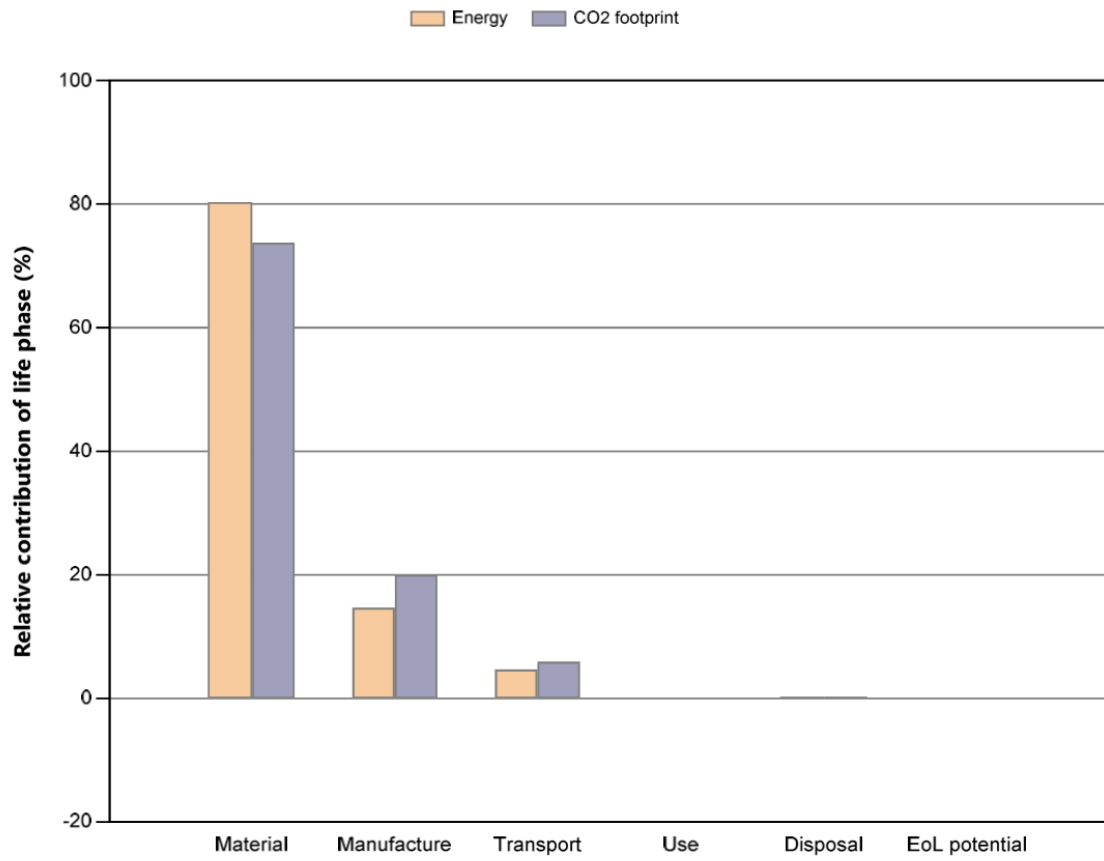


Figure 30: Eco Audit Summary

The full Bill of Materials used to construct the Eco Audit model is presented below. This was derived from the detailed component breakdown in Excel and forms the basis of the environmental analysis discussed in the following section. The Bill of Materials from the Eco Audit is also shown below.

Part Number	Part Name	Quantity/unit	Mass g	Mass per unit kg	Material	Method of Manufacture
1	Outer shell 1	1	34		ABS (C)	Injection moulding + milling (C)
2	Outer Shell 2	1	38		ABS (C)	Injection moulding + milling (C)
3	Battery lid	1	4		ABS (C)	Injection moulded (C)
4	Battery contacts	2	<0.5		Stainless steel (EE)	Die cut/metal stamping (EE)
5	Battery Spring base	1	<1		Polyurethane (C)	Injection moulded (C)
6	double mount battery spring	1	<1		Stainless steel (EE)	CNC Coiled (EE)
7	Battery springs solo	2	<0.5		Stainless steel (EE)	CNC Coiled (EE)
8	Battery connector	1	<1		Stainless steel + polycarbonate (C)	overmoulding (C)
9	Metal plate	1	<1		Stainless steel (EE)	Die cutting/metal stamping (EE)
10	Slide switch A	1	<1		Cellulose propionate/acetate butyrate (C)	Injection moulded (C)
11	Slide switch B	1	<1		Cellulose propionate/acetate butyrate (C)	Injection moulded (C)
12	Metal connector	1	<1		Stainless steel (EE)	Die cutting (C)
13	Red wire A	1	<1		Copper + pvc (C)	Extrusion (C)
14	Red wire B	1	<1		Copper +pvc (C)	Extrusion (C)
15	Very small gear	1	<1		Acetal (EE)	Injection moulded (C)
16	MOTOR	1	40		Various	Pre manufactured part
17	Long gear	1	4		Acetal (EE)	Injection moulded (C)
18	Stubby gear	1	4		Acetal (EE)	Injection moulded (C)
19	Needle arm cover	1	4		ABS (C)	Injection moulded (C)
20	Needle arm	1	22		Stainless steel (C)	Die cutting (C)
21	Fastening Base	1	10		Stainless steel (C)	Die cutting (C)
22	Sewing base	1	26		Stainless steel (C)	Die cutting (C)
23	Main pivot	1	<1		Stainless steel (C)	Milling (EE)
24	Main torsion spring	1	<1		Stainless steel (C)	CNC Coiled (EE)
25	Movement stabiliser	1	<1		Stainless steel (C)	Sheet metal stamping (EE)
26	Presser foot	1	<1		Stainless steel (C)	Sheet metal stamping (EE)
27	needle tensioner	1	<1		Stainless steel (C)	Sheet metal stamping (EE)
28	Gear main mech connector	1	<1		Acetal (EE)	Injection moulded (C)
29	needle tensioner washers	2	<0.5		Stainless steel (C)	Sheet metal stamping (EE)
30	pin	1	<0.5		Stainless steel (C)	Stamping (EE)
31	needle	1	<1		Stainless steel (C)	Metal forming (EE)
32	bobbin shaft small	1	<1		Polyurethane (C)	Injection moulded (C)
33	bobbin shaft long	1	<1		Polyurethane (C)	Injection moulded (C)
34	Extension spring	1	<1		Stainless steel (EE)	CNC Coiled (EE)
35	Compressive spring	1	<1		Stainless steel (EE)	CNC Coiled (EE)
36	primary screws pointy	3	<1		Stainless steel (EE)	cold forming (EE)
37	secondary screws recessed	2	<1		Stainless steel (EE)	cold forming (EE)
38	secondary screws short blunt	2	<1		Stainless steel (EE)	cold forming (EE)
39	tertiary screws internal	1	<1		Stainless steel (EE)	cold forming (EE)
40	bobbin thread	9	1.3		Polyester thread + polyurethane spool (EE)	Injection moulding + spinning (EE)
41	Rotary wheel	1	2		ABS (C)	Injection moulded (C)
42	needle tip protector	1	<1		Cardboard (C)	Cut from larger cardboard (C)
43	spare needle	1	<1		Stainless steel (C)	Metal forming (EE)
44	safety pins	10	0.4		Stainless steel (C)	Machined - specialised for safety pins (C)
45	needle threader	1	<1		Stainless steel (C)	Stamping (EE)
46	shear blades	2	1		Stainless steel (C)	Die cutting (C)
47	shear handle	1	<1		Pe (EE)	Overmoulded over shear blades (EE)
48	measuring tape	1	6		Polycarbonate/ppa (EE)	Paper covered in plastic (C)
49	measuring cover	1	<1		Cardboard (C)	Paper manufacturing techniques (C)
50	shear packaging	1	<1		Pe (EE)	Extrusion (C)
51	manual	1	<1		Paper (C)	Paper manufacturing techniques (C)
52	Packaging cardboard box	1	48		Cardboard (C)	Die cutting (C)
53	Bubble wrap	1	<1		Pe (EE)	Two sheets rolled over each other (G)
54	Miscellaneous packaging	1	<1		Pe (EE)	Extrusion (C)
55	Bobbin packaging	1	<1		Pe (EE)	Extrusion (C)

Figure 13: Excel Bill of Materials

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass (kg)	Energy (MJ)	%
Outer Shell 1	Acrylonitrile butadiene styrene (ABS)	Virgin (0%)	0.034	1	0.034	3.2	11.3
Outer Shell 2	Acrylonitrile butadiene styrene (ABS)	Virgin (0%)	0.038	1	0.038	3.6	12.6
Battery Lid	Acrylonitrile butadiene styrene (ABS)	Virgin (0%)	0.004	1	0.004	0.37	1.3
Battery Contacts	Stainless steel	Virgin (0%)	0.0005	2	0.001	0.073	0.3
Battery Spring Base	Polyurethane (tpPUR)	Virgin (0%)	0.0005	1	0.0005	0.041	0.1
Double Mounted Battery Spring	Stainless steel	Virgin (0%)	0.0005	1	0.0005	0.036	0.1
Battery Springs Solo	Stainless steel	Virgin (0%)	0.0005	2	0.001	0.073	0.3
Battery Connector	Stainless steel	Virgin (0%)	0.0005	1	0.0005	0.036	0.1
Metal Plate	Stainless steel	Virgin (0%)	0.0005	1	0.0005	0.036	0.1
Slide Switch A	Cellulose polymers (CA)	Virgin (0%)	0.0005	1	0.0005	0.044	0.2
Slide Switch B	Cellulose polymers (CA)	Virgin (0%)	0.0005	1	0.0005	0.044	0.2
Metal Connector	Stainless steel	Virgin (0%)	0.0005	1	0.0005	0.036	0.1
Red Wire A	Copper	Virgin (0%)	0.0005	1	0.0005	0.03	0.1
Red Wire A	Polyvinylchloride (tpPVC)	Virgin (0%)	0.0005	1	0.0005	0.032	0.1
Battery Connector	Polycarbonate (PC)	Virgin (0%)	0.0005	1	0.0005	0.053	0.2
Red Wire B	Copper	Virgin (0%)	0.0005	1	0.0005	0.03	0.1

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass (kg)	Energy (MJ)	%
Red Wire B	Polyvinylchloride (tpPVC)	Virgin (0%)	0.0005	1	0.0005	0.032	0.1
Very Small Gear	Polyoxymethylene (Acetal, POM)	Virgin (0%)	0.0005	1	0.0005	0.043	0.2
Motor Steel Components	Low carbon steel	Virgin (0%)	0.029	1	0.029	0.89	3.2
Motor Copper Components	Copper	Virgin (0%)	0.009	1	0.009	0.53	1.9
Motor Magnets	Alumina	Virgin (0%)	0.004	1	0.004	0.21	0.7
Motor Plastics	Acrylonitrile butadiene styrene (ABS)	Virgin (0%)	0.002	1	0.002	0.19	0.7
Motor Carbon Brushes	Low carbon steel	Virgin (0%)	0.001	1	0.001	0.031	0.1
Long Gear	Polyoxymethylene (Acetal, POM)	Virgin (0%)	0.004	1	0.004	0.34	1.2
Stubby Gear	Polyoxymethylene (Acetal, POM)	Virgin (0%)	0.004	1	0.004	0.34	1.2
Needle Arm Cover	Acrylonitrile butadiene styrene (ABS)	Virgin (0%)	0.004	1	0.004	0.37	1.3
Needle Arm	Stainless steel	Virgin (0%)	0.022	1	0.022	1.6	5.7
Fastening Base	Stainless steel	Virgin (0%)	0.01	1	0.01	0.73	2.6
Sewing Base	Stainless steel	Virgin (0%)	0.026	1	0.026	1.9	6.7
Main Pivot	Stainless steel	Virgin (0%)	0.0005	1	0.0005	0.036	0.1
Main Torsion Spring	Stainless steel	Virgin (0%)	0.0005	1	0.0005	0.036	0.1
Movement Stabiliser	Stainless steel	Virgin (0%)	0.0005	1	0.0005	0.036	0.1
Presser Foot	Stainless steel	Virgin (0%)	0.0005	1	0.0005	0.036	0.1
Needle Tensioner	Stainless steel	Virgin (0%)	0.0005	1	0.0005	0.036	0.1
Gear Main Mech Connector	Polyoxymethylene (Acetal, POM)	Virgin (0%)	0.0005	1	0.0005	0.043	0.2
Needle Tensioner Washers	Stainless steel	Virgin (0%)	0.00025	2	0.0005	0.036	0.1
Pin	Stainless steel	Virgin (0%)	0.0005	1	0.0005	0.036	0.1
Needle	Stainless steel	Virgin (0%)	0.0005	1	0.0005	0.036	0.1
Bobbin Shaft Small	Polyurethane (tpPUR)	Virgin (0%)	0.0005	1	0.0005	0.041	0.1
Bobbin Shaft Long	Polyurethane (tpPUR)	Virgin (0%)	0.0005	1	0.0005	0.041	0.1
Extension Spring	Stainless steel	Virgin (0%)	0.0005	1	0.0005	0.036	0.1
Compressive Spring	Stainless steel	Virgin (0%)	0.0005	1	0.0005	0.036	0.1
Primary Screws (Pointy)	Stainless steel	Virgin (0%)	0.0005	3	0.0015	0.11	0.4
Secondary Screws (Recessed)	Stainless steel	Virgin (0%)	0.0005	2	0.001	0.073	0.3
Secondary Screws (Blunt)	Stainless steel	Virgin (0%)	0.0005	2	0.001	0.073	0.3
Tertiary Screws Internal	Stainless steel	Virgin (0%)	0.0005	1	0.0005	0.036	0.1
Bobbin Thread Spool	Polyurethane (tpPUR)	Virgin (0%)	0.0065	9	0.059	4.8	17.0
Bobbin Thread	Polyester (UP)	Virgin (0%)	0.0065	9	0.059	5.2	18.3
Rotary Wheel	Acrylonitrile butadiene styrene (ABS)	Virgin (0%)	0.002	1	0.002	0.19	0.7
Needle Tip Protector	Paper and cardboard	Virgin (0%)	0.0005	1	0.0005	0.014	0.0
Spare Needle	Stainless steel	Virgin (0%)	0.0005	1	0.0005	0.036	0.1
Safety Pins	Stainless steel	Virgin (0%)	0.0004	10	0.004	0.29	1.0
Needle Threader	Stainless steel	Virgin (0%)	0.0005	1	0.0005	0.036	0.1
Shear Blades	Stainless steel	Virgin (0%)	0.0005	2	0.001	0.073	0.3
Shear Handle	Polyethylene (PE)	Virgin (0%)	0.0005	1	0.0005	0.04	0.1
Measuring Tape	Polycarbonate (PC)	Virgin (0%)	0.003	1	0.003	0.32	1.1
Measuring Tape 2	Paper and cardboard	Virgin (0%)	0.003	1	0.003	0.085	0.3
Measuring Cover	Paper and cardboard	Virgin (0%)	0.0005	1	0.0005	0.014	0.0

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass (kg)	Energy (MJ)	%
Shear Packaging	Polyethylene (PE)	Virgin (0%)	0.0005	1	0.0005	0.04	0.1
Manual	Paper and cardboard	Virgin (0%)	0.0005	1	0.0005	0.014	0.0
Packaging Cardboard Box	Paper and cardboard	Virgin (0%)	0.048	1	0.048	1.4	4.8
Bubble Wrap	Polyethylene (PE)	Virgin (0%)	0.0005	1	0.0005	0.04	0.1
Miscellaneous Packaging	Polyethylene (PE)	Virgin (0%)	0.0005	1	0.0005	0.04	0.1
Bobbin Packaging	Polyethylene (PE)	Virgin (0%)	0.0005	1	0.0005	0.04	0.1
Total				97	0.39	28	100

Figure 27 – 29: Bill of Materials: Eco Audit

9.3 Appendix 3

Semantic Differential Scale

Below is the form I used to collect data regarding the Outer Case redesign. The idea was to use a semantic differential scale to determine how users would like the product to feel. This is further explored in the Redesign Section.

The link to the form: <https://forms.office.com/e/58PnbHTrPW>

QR Code:

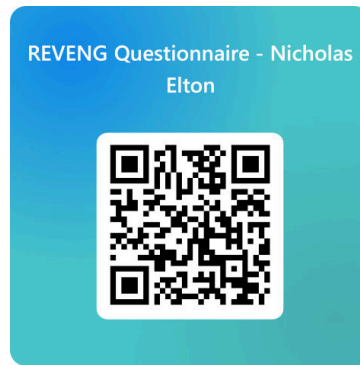
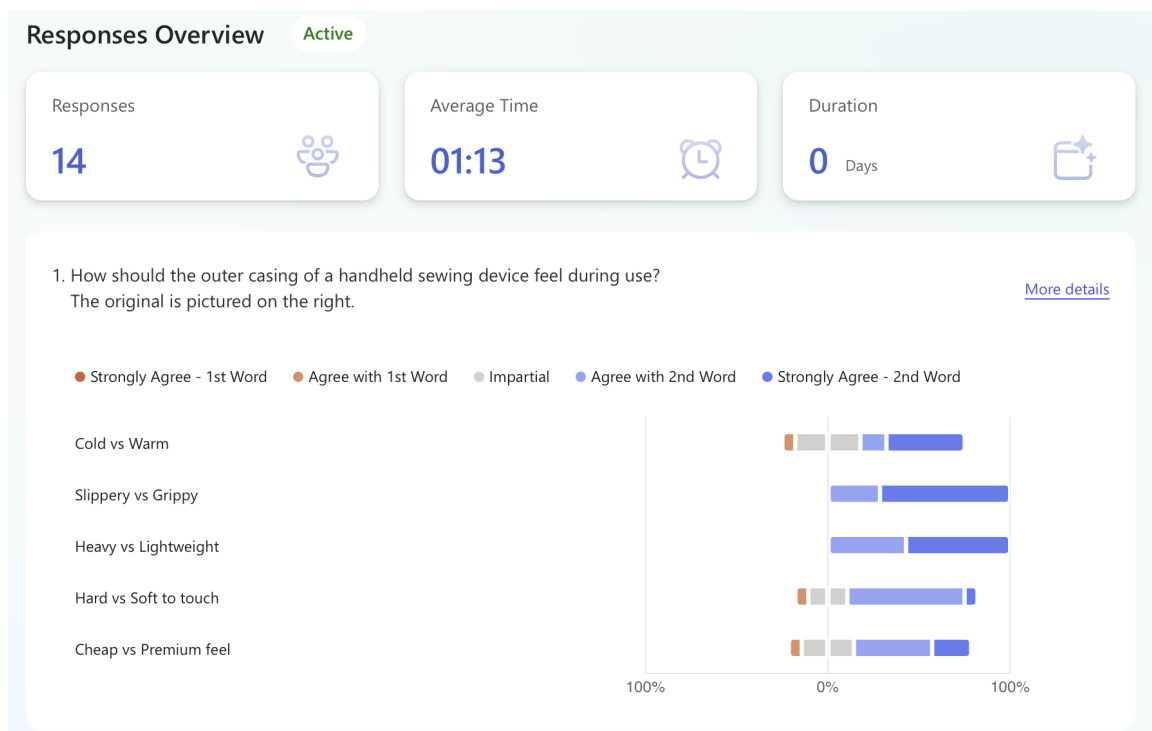


Figure 32: QR code for form: Semantic Scale

The results from the form are also laid out below:



9.4 Appendix 4

Ashby Plots

Shown below are the Ashby plots used to determine what material to use for the redesign, this is further explained in the Reverse Engineering Solutions section.

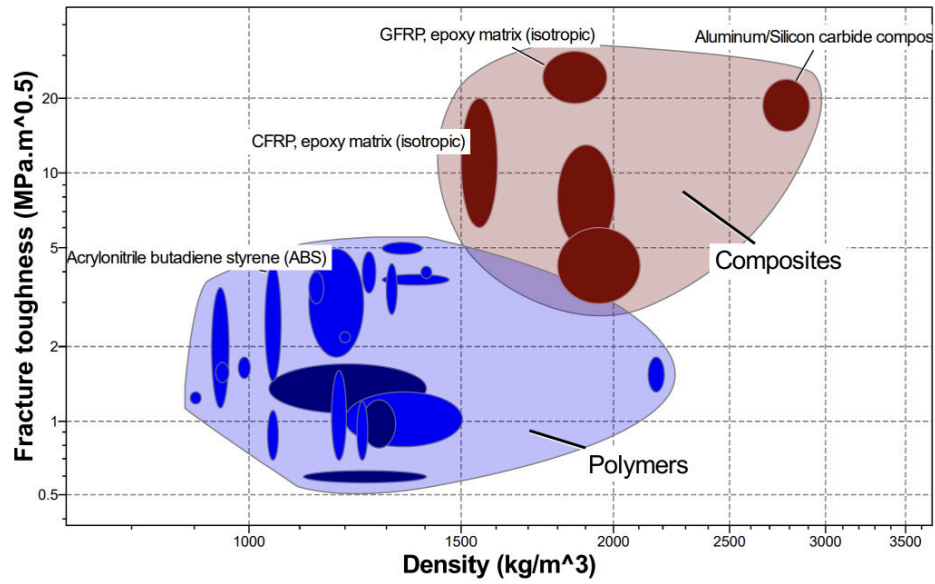


Figure 18: Ashby Plot of Outer Case Materials

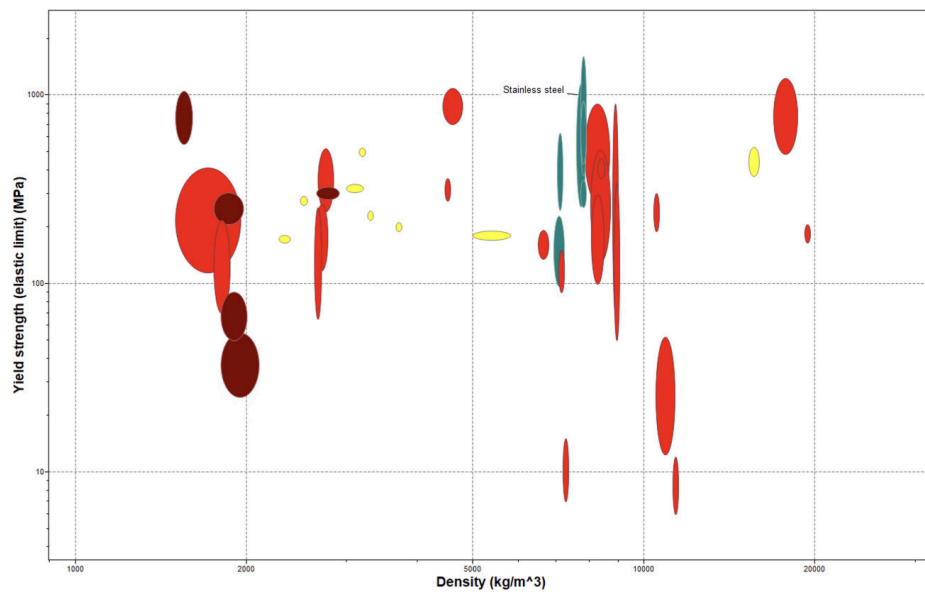


Figure 19: Ashby Plot of Sewing Mechanism Materials

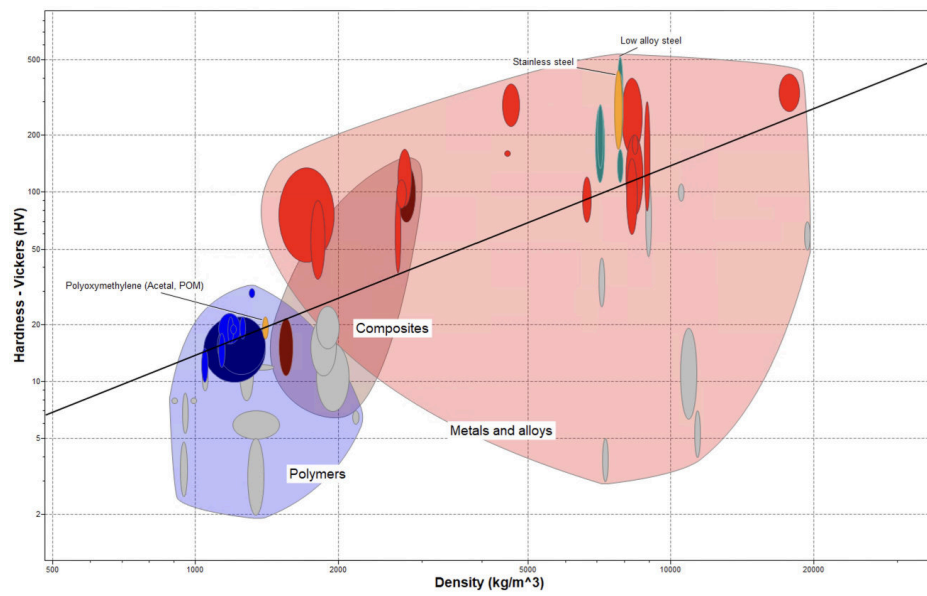


Figure 20: Ashby Plot of Internal Gear Materials

9.5 Appendix 5

Rendered Image of Outer Case Redesign



Figure 31: Render of Redesign₍₁₉₎