DESIGN AND DEVELOPMENT OF CAR’S WINDSHIELD LIFTING TOOL FOR END-OF-LIFE VEHICLE DISMANTLING PROCESS

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To all my contributor, thanks for all the contribution along this project.

ABSTRACT

Customised windshield lifting tool for dismantling end of life vehicles (ELVs) solves some significant issues such as safety issues and environmental concerns as well as efficiency issues of the dismantling process. Traditional techniques of the removal of windshields involve the use of unskilled manual labour, which is dangerous, time-consuming, likely exposes the windshields to physical damage therefore calling for an innovation. In this research, major design parameters such as adjustability, ergonomics, safety, ease of use, durability, and compatibility are incorporated into the design of the required tool. CAD software and FE analysis are employed to validate the tool's mechanical performance and functionality in different operating states. As a functional prototype of the tool, the 3D printing approach made it possible to physically interact with the designed tool and assess its functionality. The testing proved enhanced effectiveness in operation, safety of workers, and efficiency of windshield removal in comparison to the initial practices. It is also important to note that the tool is made from lightweight but durable materials like aluminium alloys and stainless steel so that it does not add to the manual stress on workers but at the same time is very durable and long lasting. The practicality and applicability to numerous automotive models appeals to the effectiveness and efficiency that is inherent in the automotive recycling business. Apart from operation significance, the windshield lifting tool helps to achieve some goals as to sustainability since the use of valuable materials allows recycling them without negative impacts on the environment. They are in harmony with the concept of the circular economy, encouraging the subsequent use of the auto part and limiting the utilization of raw material for developing automotive. This study provides a new paradigm shift in ELV dismantling as it focuses on implementation of a new approach that could ensure increased safety, effectiveness, and most importantly, environmental care. The results outlined in this study can be considered to show the remarkable roles of advanced technologies in engineering in bringing about significant changes in mainstream industries in automotive recycling. This tool was considered as a significant contribution to solving the urgent problems in ELV management and contributing to improving sustainability in the automotive industry.

ABSTRAK

Alat pengangkat cermin hadapan yang disesuaikan untuk pembongkaran kenderaan akhir hayat (ELVs) menyelesaikan beberapa isu penting seperti masalah keselamatan, kebimbangan alam sekitar, serta masalah kecekapan dalam proses pembongkaran. Teknik tradisional untuk mengeluarkan cermin hadapan melibatkan penggunaan tenaga kerja manual yang tidak terlatih, yang berbahaya, memakan masa, dan berpotensi menyebabkan kerosakan fizikal pada cermin hadapan, sekali gus memerlukan inovasi baharu. Dalam kajian ini, parameter reka bentuk utama seperti kebolehsuaian, ergonomik, keselamatan, kemudahan penggunaan, ketahanan, dan keserasian telah dimasukkan ke dalam reka bentuk alat yang diperlukan. Perisian CAD dan analisis elemen terhingga (FEA) digunakan untuk mengesahkan prestasi mekanikal dan fungsi alat tersebut dalam pelbagai keadaan operasi. Proses penghasilan prototaip fungsi alat tersebut menggunakan pendekatan cetakan 3D yang memungkinkan interaksi fizikal dengan alat yang direka dan penilaian terhadap fungsinya. Ujian membuktikan peningkatan keberkesanan operasi, keselamatan pekerja, dan kecekapan penyingkiran cermin hadapan berbanding amalan awal. Alat ini juga diperbuat daripada bahan ringan tetapi tahan lama seperti aloi aluminium dan keluli tahan karat, yang tidak menambah tekanan manual pada pekerja tetapi pada masa yang sama sangat tahan lama dan boleh digunakan untuk jangka masa panjang. Kepraktisan dan kebolehgunaan alat ini terhadap pelbagai model automotif menyerlahkan keberkesanan dan kecekapan yang terkandung dalam perniagaan kitar semula automotif. Selain kepentingan operasi, alat pengangkat cermin hadapan ini membantu mencapai matlamat kelestarian kerana penggunaan bahan bernilai membolehkan kitar semula tanpa memberi kesan negatif kepada alam sekitar. Ia selaras dengan konsep ekonomi kitaran, yang menggalakkan penggunaan semula bahagian automotif dan menghadkan penggunaan bahan mentah untuk pembuatan automotif. Kajian ini menyediakan paradigma baharu dalam pembongkaran ELV kerana ia memberi tumpuan kepada pelaksanaan pendekatan baharu yang dapat memastikan peningkatan keselamatan, keberkesanan, dan yang paling penting, penjagaan alam sekitar. Hasil yang digariskan dalam kajian ini menunjukkan peranan luar biasa teknologi canggih dalam kejuruteraan dalam membawa perubahan ketara kepada industri utama seperti kitar semula automotif. Alat ini dianggap sebagai sumbangan penting dalam menyelesaikan masalah mendesak dalam pengurusan ELV dan meningkatkan kelestarian dalam industri automotif.

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LIST OF ABBREVIATIONS

ELV	-	End-of-life vehicle
LF	-	Load factor
LsF	-	Loss factor
NAP	-	National Automotive Policy
EPR	-	Extended producer responsibility
EU	-	European Union
PST	-	Post-shredder technology
PVB	-	Polyvinyl butyral
PET	-	Polyethylene terephthalate
UV	-	Ultraviolet
LiFFT	-	Lifting fatigue failure theory
CAD	-	Computer-aided design
FEA	-	Finite element analysis
2D	-	Two-dimensional
3D	-	Three-dimensional
FDM	-	Fused Deposition Modelling
PLA	-	Polylactic Acid

CHAPTER 1

INTRODUCTION

1.1 Background

End-of-life vehicles (ELVs) are the last in a series of vehicles that indicate when a vehicle has outlived its useful life because of things like age, wear and tear, or irreversible damage. But the story of ELVs doesn't end with their disposal. It's a crucial point when industrial operation and environmental responsibilities collide.

Due to the advancement of technology in automotive sector is rapid hence making a substantial number of cars in Malaysia becoming obsolete in a one-year period. The ELVs if not handled well often cause serious concerns to the environment and cost the industries a lot of money. Toxic materials like lead, mercury, and automobile fluids are expose in the potential to contaminate soil and water are environmental issues. Lack of proper management of ELVs leads to recycling loss of useful materials including metals, plastics, glass among others which have a ripple effect of costing the Malaysian economy millions of tonnes in resources annually.

Economical ELV recycling enhances resource conservation, contributes to minimizing energy consumption, and encourages the development of the circular economy to recognize the role of proper ELV disposal in mitigating environmental and financial impacts. Additionally, through high speed of automotive industry development new technologies, the lifespan of old car tends to shorten. This demonstrates the significance that is associated with ELVs management with the aim of ensuring that the use of hazardous substances in making new automobiles cannot happen.

It is correct that batteries, oils and fluids in ELVs require careful handling as they present a threat to soil and water if not disposed appropriately and ELVs management has a damaging impact on the environment. ELV recycling however, brings a window of opportunity to reduce these risks and reduce the energy and raw material used to manufacture new cars if managed appropriately. In managing through these issues, the management of ELVs remains a key part of sustainable manufacturing in the automotive industry, and a core perception of environmental responsibility spanning throughout the automotive end of lifecycle.

1.2 Problem Statement

ELV disassembly is fraught with difficulties, especially when it comes to removing vital parts like windshields because hand tools techniques are used, current windshield removal methods are frequently labour-intensive, time-consuming and sometimes dangerous for workers. Therefore, there is a pressing need for the design and development of an innovative windshield removal specifically tailored for ELV dismantling process.

A novel windscreen lifting tool that is specifically designed for the ELV dismantling operation is urgently needed. This tool should give priority to crucial elements such as effectiveness, security, user comfort, and ecological sustainability. An innovative portable windscreen lifter designed specifically for ELV disassembly procedures would effectively tackle these pressing concerns, offering a solution that improves operational efficiency and worker safety while also promoting environmental stewardship.

An appropriate windscreen lifting tool has the potential to greatly simplify the dismantling procedure of ELVs. A gadget that reduces the need for manual labour would decrease worker tiredness and lower the risk of accidents, resulting in a safer work environment. By implementing ergonomic design concepts, the tool can be made more user-friendly, hence minimizing physical strain on workers. The emphasis on ergonomics is essential for preserving the long-term health and productivity of workers.

In addition, enhancing the efficiency of windscreen removal would accelerate the total disassembly procedure, enabling faster turnaround times and improved throughput. The increase in efficiency could result in cost reductions and greater profitability for enterprises engaged in ELV recycling. The creation of a dedicated windscreen lifter is in line with wider sustainability goals. Efficient dismantling and recycling of ELVs are necessary for waste reduction and mitigating the environmental consequences of vehicle disposal. This instrument would enable the secure and effective lifting of windshield, thereby promoting the appropriate recycling and disposal of automotive glass and other components. This would contribute to environmental conservation initiatives.

To summarise, there is a strong and urgent requirement for a cutting-edge device that can lift windscreens during the dismantling of ELVs. This technology would enhance both operational efficiency and worker safety, while also promoting the sustainable management of ELVs. Creating a portable, efficient, ergonomically built, and safe windscreen lifter would be a major advancement in tackling the difficulties of ELV disassembly, ultimately promoting a more sustainable and responsible approach to vehicle recycling.

1.3 Research Objectives

The main aim of this research is to develop new tools for car's windshield remover with enhance overall operating efficiency. Specifically, the objectives are as follows:

i. To identify key parameters for designing ELV's windshield lifting tool from research.

ii. To design and analyse of ELV's windshield lifting tool using CATIA V5, and Ansys

iii. To develop a prototype of ELV's windshield lifting tool by 3D printing.

1.4 Scope of Research

The scope of this research are as follows:

i. The design should be user-friendly.

ii. The design will be focusing on the car's windshield lifting tool.

iii. Structural analysis is to determine the structural performance.

iv. Investigation of load profiles of residential, commercial and industrial load segments to determine load factor (LF) and loss factor (LsF) were considered in the simulation models.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Automobile production in the Malaysian model is one of the dramatic transformations of industrial growth of the country. The development of the automotive industry in Malaysia began in the 1960s, making it a significant industrial sector, boosting economic growth and improving the technology. In the same regard, due to the ever-expanding automotive industries in Malaysia, ELV management has become an even more crucial issue because the ELVs contain hazardous substances like lead, mercury and cadmium that if disposed of properly pose a great threat to the environment since they can leach out into the soil and water systems. The case of ELVs is however not an exception and Malaysia has elaborated measures to effectively address this issue as outlined below.

As a way of promoting take-back programs and establishing recycling centres, the National Automotive Policy (NAP) under the legislation enacted in 2006 contains guidelines that deal with the proper handling and disposal of ELVs. Additionally, in an attempt to influence the sustainability and eco-friendly approach towards automobiles in Malaysia the government has sought to develop and establish the standards for environmentally sound management of ELV.

2.1.1 Definition of ELV

ELVs include the flow and cycle of disposing and recycling and its relation to the surroundings. Automobiles are not only restricted to these features, but they do mark an important phase in the life cycle of a car. ELVs accordingly mean "end-of-life vehicles", that are cars that have been deemed no longer operative for any use apart from recycling. Due to their influence on the environment as well as the problems it presents towards the timely implementation of environmentally friendly systems of waste disposal, ELVs have attracted much attention amongst policymakers as well as scholarly researchers. The abbreviation ELV stands for End-of-Life Vehicle and its interpretation in different literary works may also differ. However, it usually refers to a motor vehicle that needs to be dismantled, reclaimed or disposed since it is old and/or damaged or because it no longer serves the intended function. This description highlights the details of ELVs, which denote the specific conditions of the car while asserting the political and economic conditions that determine the car's final state in its lifecycle.

Scientists have defined ELVs in several ways due to the cross-sectional nature of research in this area. Therefore, several definitions have been used regarding the disposal of these vehicles. According to the coverage of environmental science and engineering literature, ELVs are often characterized as possible ecological impacts. Such factors as the emissions, the presence of hazardous substances and, or the reusability are invoked in this assessment. On the other hand, the field of transportation science and policy research might turn their focus towards new ways of studying the practices and governmental policies regarding ELV management and disposal, or car recycling. Secondly, differences in legal frameworks regarding car disposal policies and the cultural perspectives towards car disposal may provide different interpretations of the concept taking into consideration that definitions may vary depending on the regional or national context.

A very, very big ELV scrapyard containing many cars in many different states and conditions as can be seen in **Figure 2.1**. It is identifiable in the overhead shot by identifying the number 1. They are all parked and spread out as randomly as one can imagine on a piece of ground abundantly furnished with grass: despite the differences in make, model and colour, the cars huddle together in the closest proximity possible. A considerable number of automobiles bear clear signs of severe wear including rust, broken doors and windows, and lack of some spare parts, among others which is a clear indication that they have been left for some time without use. The confusion in automotive waste disassembly and collection is conveyed by the disorderly nature of the wires, tubing, and metallic pieces that the artwork is composed of, thus emphasizing the need for proper procedures that will help reduce the adverse effects of automotive waste on the environment. This entails reducing the emission of gases and other harmful substances produced while undertaking vehicle processing and ensuring that pollutive fluids do not trickle onto the ground or into the water source.

Figure 2.1 ELV scene in Malaysia (*Gunuvim via Reddit, 2023*)

In some studies, several writers have provided various elaborate definitions of end-of-life vehicles thereby coming up with a more relative concept of this idea. As per the study conducted by Smith et al. (2018), ELVs are clarified as “motor vehicles that cannot be used for the intended operation as they are declared unfit due to several factors such as they are old, have mechanical problems or have become obsolete, and are meant for dismantling, recycling or disposal”. This concept which cuts across all the principles of ELV management also pays considerable attention to the practical dimension of utilising a vehicle and other processes that ensue. , Jones & Brown (2020) offer a clear understanding of the regulatory perspective of ELVs by describing them as “automobiles that, by law, have become useless and fall under the category of those whose disposal and recycling process is regulated.” The aforementioned definitions help in comprehending the relationship that exists between technology, government, and the environment regarding the ELVs.

2.1.2 Significant of ELV

The management of ELVs is currently a matter of increasing concern for the global community owing to its impact on the environment and activity of the economy. ELVs are a major component of automotive waste and represent a real problem for the automotive industry. This raises concerns with regards to the over-utilization, degradation, and proliferation of resources which require responsible and efficient use. This paper aims at discussing the relevance of mitigating ELVs and exploring some of the recent studies highlighting this issue.

Smith et al. (2019) reviewed the literature to determine the environmental consequences resulting from ELVs; therefore, the scenario depicts the consequences when ELVs are involved in the emission of pollutants to the air and water, pollution of the soil, and emission of greenhouse gases. The study also provide real life demands that indicate that ELVs emit huge amount of such environmentally antagonistic factors as heavy metals and organics. They are also capable of staying in the environment and might in some stature affect the welfare of human beings and the environment. Moreover, the management of ELVs regarding their ability of recycling and disposing has been poor and eventually contributes to vomiting rare resources (Jones & Brown, 2020). Inability to manage ELV yields such a circumstance leading to severe economic consequences when disregarded.

According to the World Bank study conducted in 2021, the problem area is the ineffective management systems for the ELVs leading to the failure to obtain adequate resources and, thus, slower economic progress. ELVs contain a broad variety of components such as steel, aluminium, polymers which are all recyclable in one way or another while many of the constituent parts can be recycled approximately 4-5 times. These resources cannot be obtained thus financial loses are experienced and dependence on these substitute materials increases the industrial expenses and it also degrades the environment (Chen & Wang, 2023).

It has been ascertained that appropriate regulatory measures as well as policy interventions are pivotal in the management of ELVs. Zhang et al. (2022) performed study highlighting the main factors of extended producer responsibility (EPR) schemes, deposit-refund systems, and eco-design standards to promote usable strategies for ELVs' sustainable management. The task of collecting, recycling and disposing are followed from manufacturers under the EPR. It is a form of encouragement intended for the manufacturers of automobiles as manufacturers are forced to design automobiles while bearing in mind the consequences that the automobiles will present at the end of their useful life. Moreover, deposit-refund systems make people bring ELVs back to certain facilities to regain the amount they were charged for the product in the first place, which helps to create a more cyclic method of utilization of resources (Wu & Li, 2020).

There are macro factors which can be addressed to in order to indicate the opportunities with the technological aspect of ELV management and its efficiency and environmentally friendly rates. The analysis presented in the paper aims to determine whether automation, artificial intelligence, and other data tools can improve the efficiency of dismantling and recycling of ELVs. Automated disassembly of ELVs further aids in the rapid and complete disassembly of such vehicles to recuperate valuable materials, all the while reducing the utilization of manpower and its consequent negative impact on the environment. Moreover, the application of predictive analytics should improve ELV recycling outcomes as it would identify the material of reconstructing value and probable fractions, ultimately leading to optimal resource utilization and incremented profitability (Gupta & Singh, 2021).

2.1.3 Practice of ELV

ELV management is the behavioural process that prevents environmental degradation and promotes the utilization of material resources. To eliminate pollution of the surroundings, the process often involves the car being de-registered for traffic and components like batteries, lubricant and air-bag systems are typically dismantled (Campbell, 2021). Due to the inability to properly dispose of these materials they have adverse effects on the environment, for instance polluting the soil and even water hence making this first step significant. After that, the car is stripped, that is the body is opened to remove all that can be salvaged and sold or used in other cars. This is a crucial step as it helps to reduce consumption as it cycles, preserving the useful life of elements of vehicles hence reducing the demand for new ones (European Commission, 2020). In addition, recyclability of parts can bring an inexpensive supply of quality spare parts for vehicle refurbishing and maintenance (Findeis et al., 2018).

The rest in all these steps construct the vehicles, which is largely made of metals, in the next stage reduced to small particles by shredding. After that, the shreds are sorted into iron-based, those which are not iron-based, polymers, and other materials through advancements techniques like flotation, eddy current separation, and magnetic separation (Zhao et al., 2021). To make these recovered resources more circular rather than linear in their cycle, the metals coming from the recycling process undergo smelting and then are reintroduced into production. This stage developed above is especially significant as it supports conservation of resources besides reducing the detrimental effects that arise from extracting and processing raw materials for production. These actions can be considered an implementation of the circular economy concept (Vermeulen et al., 2018).

Since the ELV Directive's introduction, the European Union (EU) has led the world in ELV management. According to this 2000 legislation (European Parliament and Council, 2000), by 2015, an ELV's weight must be recovered or reused at least 85% of the time, with a minimum recycling rate of 95%. By the year of 2019, recovery rate has reached 94% and recycling rate has reached 94.5%. These figures show that EU has surpassed the legislatives targets. The **Figure 2.2** show the component of the car being separate into several process. In order to prevent hazardous chemicals from contaminating recyclable materials, the directive also mandates the removal of airbags, batteries, and oils prior to the shredding process. Consequently, the EU has witnessed notable advancements in recycling rates and the creation of novel recycling technology, such as sophisticated shredding and material separation methods.

Figure 2.2 ELV process (*Vardhman Auto Recycling, 2024*)

Many case studies have been conducted to examine the effectiveness and profitability of ELV techniques from an ecological perspective. According to the European Commission (2020) on the rationale of ELV directive recycling rate has highly improved and the proportion of the hazardous material in automobiles has reduced. What has increased is the overall percent of the vehicle material that is effectively captured and recycled, which is emblematic of such developments. In the same way, the study conducted by Zhao et al. in 2021 also points towards the general enhancements in shredding and sorting technologies in recovering more materials in better rates and thereby reduced the burden on the environment for the disposal of vehicles with reduced dumping of garbage in the landfills and reduced demand for raw materials.

In developing nations, ELV management is still changing. The government of Malaysia has recognized the necessity of implementing organized ELV management guidelines. ELV disposal is currently handled by the informal sector in Malaysia, according to Kamaruddin et al. (2021), which contaminates the environment and results in ineffective material recovery. Malaysia is developing comprehensive laws, such as car de-registration, proper disposal of hazardous waste, and the encouragement of recycling companies, to solve these issues. It is anticipated that the adoption of these policies will improve ELV management's sustainability and bring Malaysia into compliance with global best practices.

Notwithstanding these developments, there are still difficulties in putting ELV practices into practice. Continuous considerations include making sure that laws are applied uniformly in all areas and enhancing the profitability of recycling businesses. Furthermore, the recycling industry faces additional hurdles as a result of the modern vehicle's developing design, which incorporates more complicated materials and technology (European Commission, 2020). To tackle these obstacles, it is imperative to persist in innovating, allocate resources towards recycling infrastructure, and create novel technologies that can adapt to the evolving vehicle composition (Ferrão & Amaral, 2018).

In conclusion, market dynamics, infrastructure, and legal frameworks all have an impact on how ELV management is practiced, which differs greatly throughout regions. Developed nations with strong mechanisms in place that give priority to resource recovery and environmental protection include the EU and Japan. On the other hand, developing nations like China and Malaysia are currently putting their ELV management strategies into practice and improving them. The significance of sustainable ELV management strategies is highlighted by the global trend towards more stringent environmental rules and higher recycling targets. In order to overcome the obstacles related to ELV management and realise the full range of environmental and economic benefits, it will be imperative to collaborate internationally, execute policies effectively, and engage in continuous innovation.

2.2 Dismantling Practice of ELV

Dismantling procedures for ELVs are crucial for controlling the lifecycle of automobiles, guaranteeing environmental sustainability, and maximising resource recovery. With these procedures, reusable materials and pieces from vehicles that have reached the end of their useful lives are recovered through a sequence of methodical steps. De-pollution is an important first stage in the disassembly process that entails the safe removal and disposal of hazardous chemicals such lubricants, coolants, batteries, and airbags. The EU's ELV Directive requires this procedure in order to prevent environmental contamination and maintain safety. It states that de-pollution must be carried out in approved treatment facilities (Chen & Lv, 2019).

Component recovery comes next in the disassembly process after de-pollution. Engines, gearboxes, and electronic modules are among the valuable parts that are carefully removed from the car. The circular economy can be advanced and the need for new parts can be decreased by refurbishing and reselling these parts (Kumar & Kothari, 2020). Through the sale of these reconditioned components, this technique not only conserves resources but also generates income. Following the recovery of the precious components, material segregation is applied to the remaining vehicle shell. Materials like glass, polymers, and metals are separated in this process. In order to maximise the quantity of material that may be recycled or reused, advanced sorting technologies, such as automated dismantling lines and sensor-based sorting, improve the efficiency and accuracy of material recovery (Liu, Guo, & Guo, 2018).

The car is then shredded once the materials have been separated. During this procedure, the car is broken down into smaller parts, which are subsequently further divided with the aid of post-shredder technology (PST). PST is used to group the shredded materials into different groups, including polymers, miscellaneous materials, and ferrous and non-ferrous metals. In order to maximise the recovery of valuable materials from the vehicle, this procedure is essential (Park & Jeong, 2020). Ultimately, recycling facilities get the separated materials. While plastics and other materials are either recycled or carefully disposed of if they cannot be economically recovered, metals are melted down and used again in manufacturing. This thorough recycling procedure not only lessens the impact that ELVs have on the environment, but it also conserves resources and generates revenue from the sale of recovered materials (Zhang & Zhang, 2021).

Thus, efficient ELV dismantling procedures are essential to the long-term administration of vehicle end-of-life procedures. These methods, which include systematic de-polluting, component recovery, material segregation, and recycling, reduce environmental harm, preserve resources, and generate employment possibilities. ELV dismantling is a vital part of contemporary waste management and sustainability initiatives because of the application of cutting-edge technology and adherence to regulatory standards, which further improve its efficiency and effectiveness (Abu-Dahrieh, Al-Mufadi, & Al-Rub, 2018).

2.2.1 Benefit of Dismantling ELV Part

Dismantling ELV parts offer a multitude of benefits across environmental, economic and social dimensions. These benefits highlight how crucial it is to create and maintain effective ELV recycling and dismantling systems.

Environmental protection has two key elements which is reducing pollution and promoting resource conservation, both of which are achieved through the disassembly of ELVs. Cars include a lot of hazardous materials, such as coolants, batteries, lubricants, and refrigerants. These materials have the potential to critically pollute land and water if they are not handled correctly. Hazardous materials may be safely removed and disposed of by carefully disassembling ELVs to prevent environmental degradation (Zhu et al., 2020). Disassembly also opens the door for the recovery and recycling of valuable parts such as metal, plastic, and glass. Recycling serves to lessen the detrimental environmental consequences of mining and manufacturing processes, such as energy usage and greenhouse gas emissions, by reducing the requirement for virgin raw materials (Liu et al., 2019).

Recycling ELV items also helps to protect the environment's natural resources. For example, since glass can be recycled and polyvinyl butyral (PVB) can be reclaimed from windscreens, the risks associated with the depletion of the natural resources necessary for glass production are minimized as well as other manufacturing costs are also cut down. Additionally, by dismantling ELV windscreens, it provides assurance to regional legal standards that there are rules in place that require recycling of certain vehicle parts, to avert any legal implications (Dhir et al., 2019). By reducing the quantity of garbage disposed in landfills, recycling ELV materials and components also supports the development of more ecologically friendly waste management practices (Yang et al., 2021).

There are significant financial benefits to disassembling ELVs. Reusable parts that can be recovered from disassembled cars offer a cheap source of parts for auto maintenance and repairs. This facet of the circular economy promotes affordable car ownership as well as the automotive repair sector, which gains from the accessibility of high-quality, reasonably priced parts (Zhu et al., 2020). Additionally, the sale of recycled goods—like metals and plastics—raises a substantial profit that helps the companies that recycle and resell these products.

The recycling and disassembly of ELVs is a vital sector for job generation as well. It includes a broad range of tasks like material and part collecting disassembly, recycling, and resale. According to Liu et al. (2019), these operations necessitate a varied workforce since they offer job opportunities across a range of industries, from sales and distribution of recovered products to specialized labour in dismantling operations. In areas with high unemployment rates, the creation of jobs can be especially advantageous as it promotes economic growth and stability.

Furthermore, governments and municipalities may save money if ELVs are managed well. Communities can cut waste management expenses and use the money saved to fund other public services and infrastructure upgrades by encouraging recycling and minimizing the amount of waste that is dumped in landfills (Yang et al., 2021). Socially, better public health and safety are a result of properly decommissioning ELVs. Improper management of hazardous compounds included in ELVs can lead to significant health problems for populations by contaminating the air, land, and water. The deconstruction procedure safeguards human health and averts potential health emergencies by making sure these compounds are removed and disposed of safely (Zhu et al., 2020).

By offering jobs to a wide range of people, especially those from disadvantaged neighbourhoods, the ELV dismantling and recycling sector also promotes social inclusion. By providing steady and possibly long-term work possibilities, this inclusion fosters social fairness and aids in the reduction of poverty (Liu et al., 2019). Vocational training programs are also frequently used in business to help workers acquire useful skills that improve their employability and career prospects in the manufacturing and recycling industries.

2.2.2 Challenge in ELV Dismantling Practice

Dismantling ELVs poses a few difficulties that affect the process's effectiveness as well as the sustainability of the environment. One of the main obstacles is the variety in car designs, which makes disassembly more difficult. Standardizing disassembly methods is challenging because modern vehicles are built with a wide variety of materials and complex components (Georgiadis & Athanasiou, 2019). Because of this diversity, dismantlers need to have a wide range of makes and models under their belts, which calls for significant training and experience. The process of disassembling cars is made more difficult by the growing use of sophisticated materials including composites, high-strength steels, and electronic components. For correct disassembly, these materials frequently call for specific tools and methods, which adds to the time and expense involved (Sodhi & Reimer, 2019).

Budgetary restrictions pose yet another major obstacle to ELV disassembly. The profitability of dismantling operations can be impacted by the volatile scrap material market pricing, which deters companies from engaging in the activity (Ardente & Mathieux, 2020). The financial gains from disassembling and recycling may not be enough to offset expenses in an environment where market values for metals and other recyclable commodities are low. It is difficult for dismantling operations to plan and invest in the necessary infrastructure and equipment because of the unpredictability of the economy. Furthermore, the initial outlay required to establish a dismantling facility—which involves purchasing land, equipment, and experienced labour—may be unaffordable, especially for small and mediumsized businesses (SMEs) (Zhang et al., 2018).

ELV disassembly is further complicated by regulatory compliance. Dismantlers must negotiate a complicated legal environment because different nations have different laws governing the recycling, disposal, and dismantling of ELVs (Santini et al., 2020). Adherence to these standards frequently demands substantial administrative labour and may result in extra expenses. For example, the End-of-Life Vehicles Directive in the European Union requires that a minimum portion of the vehicle's weight be recycled or reused, which forces dismantlers to engage in cutting-edge recycling techniques and technologies (Huang et al., 2018). Moreover, strict laws governing international trading in recyclables have an impact on the dynamics of the recycled material market and the global supply chain.

Opportunities exist to improve the automobile industry's sustainability through recycling materials from ELVs, such as thermoplastic vulcanizates and composites altered with waste rubber (Wu et al., 2023). In order to advance a circular economy in the plastics sector, techniques for recycling waste materials such as polyethylene terephthalate (PET) into useful chemicals must be developed (Yang et al., 2022). Additionally, research and scientific information have a crucial role in promoting the adoption of sustainable practices in sectors such as leather manufacturing, according to studies on the drivers of sustainable manufacturing practices (Moktadir et al., 2018). The incorporation of eco-innovation and circular economy concepts in sectors such as the polyurethane industry underscores the necessity of tackling obstacles and harnessing catalysts for sustainable methodologies (Schultz & Reinhardt, 2022).

2.3 ELV Windshield

A car's windshield in **Figure 2.3**, also called a windscreen, take action as the front glass, shielding the passenger from the elements including wind, bugs, debris, and bad weather while also giving the driver essential view. A windshield is usually made of laminated safety glass, which is made up of two layers of glass with a layer of PVB sandwiched in between. This reduces the risk of injury from flying shards of glass shatters because the glass stays adhered to the PVB layer. (National Highway Traffic Safety Administration, 2024). Because it keeps passengers inside the car and keeps foreign items from entering the inside, this design element is essential for ensuring safety during collisions (Auto Glass Safety Council, 2024).

Figure 2.3 Car’s windshield (*Miracle Auto Glass Center, 2024)*

Besides its protective function, the windshield plays a crucial role in maintaining the structural integrity of the car by upholding the roof and keeping the car's frame rigid. This is especially crucial in rollover accidents, as the windshield keeps the roof from collapsing (Car and Driver, 2024). In order to prevent ultraviolet (UV) rays from damaging the interior of the car and the occupants from sun damage, modern windshields frequently have UV protection built in (Auto Glass Repair Network, 2024). In order to improve driving comfort and safety, they can also be tinted to reduce glare, have built-in heating components to defrost or de-ice the glass in cold weather, and include acoustic layers to reduce noise within the car (Consumer Reports, 2024).

Figure 2.4(a) indicates a schematic for automotive windshield glass and **Figure 2.4(b)** indicates a component of automotive windshield glass. **Figure 2.4(a)** indicates that automotive windshield glass consists of five functional layers, (i) shatterproof layer, (ii) UV protection layer, (iii) noise isolation layer, and (iv) film formability layer. In some cases, a permeability 5th resistance layer is attached to windshield glass. From a major material constituent perspective, the automotive windshield glass consists of basic three layers, i.e., (i) tinting film layer (ii) interior glass layer, and (iii) PVB interlayer. **Figure 2.4(b)** indicates that automotive windshield glass is made from four important materials makeup, i.e., (i) glass, (ii) PVB, (iii) tinting film, and (iv) rubber. All four materials together provide visibility, sound isolation, UV-filtration, shielding, and reinforcement to automotive windshield glass. To recover (i) glass, and (ii) PVB a complete mechanical separation process and material recovery process has been developed and reported in this paper.

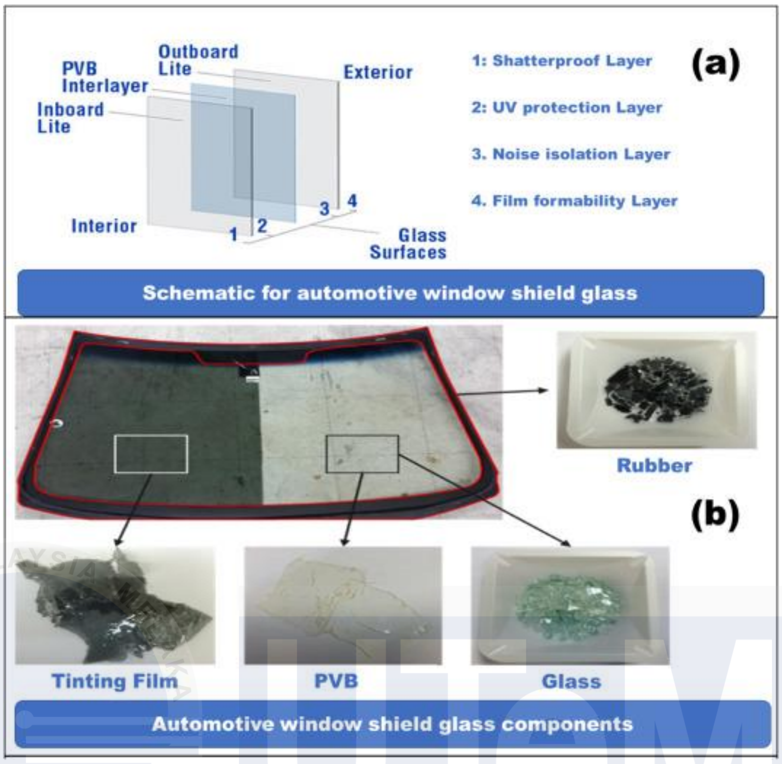

Figure 2.4 (a) Schematic for automotive windshield glass
(b) Component for automotive windshield glass.
(*Zhifu et al., 2021*)

2.3.1 Material of Windshield Lifting Tool

It is crucial to recognize that windscreens are usually composed of laminated glass, which is two layers of glass linked together with a layer of PVB sandwiched in between, in order to properly develop a windscreen lifting tool (Choi et al., 2018). PVB is often used as an interlayer material in safety glass, namely in automobile windscreens (Brendgen et al., 2021). Acquiring this understanding is essential for the creation of instruments that can securely lift and manipulate windscreens.

Research in the automotive sector has concentrated on several tools pertaining to windscreens, such as investigations into wiper mechanisms used in automotive applications, with the aim of highlighting the significance of efficient windscreen cleaning equipment

(Sharveswaran & Nirmal, 2020). The lack of windows on automobiles at that period posed obstacles for early windscreen cleaning instruments, emphasizing the need for inventive solutions to overcome these limits.

When developing equipment for lifting and handling materials such as windscreens, it is essential to take into account ergonomic factors in order to avoid musculoskeletal injuries. The Lifting Fatigue Failure Tool (LiFFT) has been developed to evaluate the risk associated with manual lifting operations using fatigue failure theory (Gallagher et al., 2018). These gadgets aid in determining the amount of compressive force exerted during lifting tasks, hence assuring the safety of personnel who are handling large things such as windscreens.

Tools based on observation have been created to measure ergonomic exposure in different sectors, such as e-waste recycling. These tools emphasize the need to prioritize user safety and comfort while performing material handling duties (Acquah et al., 2020). Utilizing ergonomic gear may greatly diminish the likelihood of accidents and enhance labour productivity, particularly when considering the physical strain involved in lifting windscreens.

The material of the tool has been selected based on several studies and consideration that include the strength, weight and ability of the material under test to withstand corrosion and lastly, the cost of the material. The vertical column has been chosen to be of high strength aluminium alloys as they are highly rigid and light. The base structure and horizontal arm are made from stainless steel that assure high anti-corrosive feature as well as longevity. Furthermore, polyurethane material has been chosen for the wheels so that it can easily fit with the rest of the components and to eliminate a noisy set when disassembling. Combining all these materials enhances the tool's performance, reliability, and durability.

Moreover, automobile windscreens have been deemed suitable for post-accident dose reconstruction at nuclear facilities owing to their distinctive characteristics, including the ability to preserve critical information even after accidents (Wahib et al., 2020). It is crucial to use windscreen lifting equipment that provides structural support and extra features tailored to individual application needs.

2.3.2 Application of Windshield Lifting Tool

With the help of windscreen lifting equipment, car repair sector has gained enhanced ideas on efficiency, safety measures, and precision. Traditionally, the process of auto replacement of windscreens required days and employed several specialists who operated heavy glass panels as depicted in **Figure 2.5**. There was a relative danger of injury in this method apart from yielding varying quality installations. However, getting more to the specifics of this procedure, windscreen lifting implements have been developed to adapt to the best and effective devices. This equipment which often uses a combination of vacuum cups, and mechanical or pneumatic arm enables a lone operator to easily pull off windscreens with utmost ease and without any form of exertion, installing them in the process.

Figure 2.5 Manual handling windshield lifting tool (*AAA Automotive, 2023)*

An important advantage of utilizing windscreen raising equipment is the enhancement of installation quality. Accurate alignment is essential for maintaining the structural integrity of the vehicle and ensuring the proper operation of safety equipment such as airbags. For instance, airbags depend on the windscreen to offer assistance during activation, and any misalignment can undermine their efficacy. Smith and Johnson (2020) state that the utilization of lifting tools guarantees the proper installation of windscreens in accordance with the manufacturer's regulations, hence upholding the safety standards of the vehicle.

Furthermore, the utilization of windscreen lifting tools not only provides operating advantages but also leads to a decrease in material waste. Damage to glass during manual installation is a frequent issue, resulting in higher expenses and negative effects on the environment. As stated by Garcia and Martinez (2020), using these tools to handle glass reduces the chances of it breaking. This leads to financial savings and a smaller environmental impact for repair shops (Garcia & Martinez, 2020).

Furthermore, the benefits in terms of efficiency achieved by utilizing these technologies are significant. The conventional practice of manually lifting and placing windscreens is not only time-consuming but also susceptible to mistakes. By using lifting tools, the installation procedure becomes more efficient, hence decreasing the time needed for each task. According to Smith and Johnson (2020), these solutions have the capability to reduce installation time by up to 50%, enabling service providers to enhance their productivity and manage a greater number of tasks within the same timeframe. The efficiency of the service results in cost benefits for both the providers and consumers, as faster turnaround times lead to reduced labour expenses and less vehicle downtime.

Ergonomically, the mechanical lifting equipment used to lift windscreen is highly effective in reducing risks to the workers. Technicians who are involved in the handling of windscreens are perilous of falling victim to musculoskeletal injuries due to the force and bulk of the windscreen glass pieces. In the same year, Brown (2019) also pointed out that thankfully, through the use of lifting equipment, the burden of lifting heavy components is relieved from technicians which in return reduces the rate of accidents at the workplace. Apart from reducing the number of incidences that result in injuries and compensation claims, this ensures that qualified workers are retained in the course.

Moreover, the windscreen lifting equipment is not only useful during the installation process and other practices that are carried out during the repair of cars but also an added blessing to the general improvement of the professionalism that is accorded to the car repair industry. Providers in the industry are also in a position to improve the quality of service offered, thus solidifying a good reputation through the use of advanced technology and service delivery systems. This may lead to improved client satisfaction and retention while increasing customer reach of other service providers who want to work with reliable providers.

Furthermore, various trends on the market concerning the use of windscreen lifting tools are confirmed by wider processes present in the automotive glass industry, characterized by tendencies towards higher automation and utilization of instruments. Due to the advancement in automotive technology, automobiles have become more intricate, and thus, the instruments and processes required in servicing must as well evolve. Windscreen lifting tools are preconditioned by the overall progressing of complex and effective mechanisms of car repair, including computer diagnosing aid, automated devices, and many other high technologies. Industry is expected to retain this trend as it continues to work towards improving on the quality and utility of its services.

To summarize, the utilization of windscreen lifting equipment signifies a substantial advancement in the vehicle repair sector. This equipment has become crucial for modern windscreen replacement due to their ability to decrease physical exertion, enhance productivity, guarantee accuracy, reduce material wastage, and incorporate cutting-edge technical functionalities. With the ongoing advancement of technology, it is anticipated that these instruments will grow increasingly sophisticated, hence expanding their usefulness and advantages.

2.3.3 Current Product of Windshield Lifting Tool

Table 2.1 highlights the basic differences in functionality between two common types of windshields lifting tools that currently use in the market. The vacuum suction cup is simpler and relies on pressure, while the heavy-duty version offers additional mechanical or pneumatic features for handling heavier or more challenging tasks.

Table 2.1 Current product windshield lifting tool

Tools	Functions
Vacuum suction cup 	Creates vacuum seal using atmospheric pressure
Heavy-duty suction cup 	Combines vacuum with mechanical or pneumatic features

2.4 Design Parameter for Windshield Lifting Tool

Recycling and the subsequent disposal of ELVs constitute a continuous process that hinges on the proper and environmentally friendly disposal of parts such as windscreens. In this case, at some point when the car is no longer usable for operation it will have to be dismantled so as to remove various parts like the windshield and categorize them appropriately. In this case handling of windscreens in the conventional manner poses various risks and challenges which may lead to instances of material damage, injury and less than optimal returns on recycling hard earned resources. Consequently, the use and invention of specialized windscreen lifting tools in windscreen repair and replacement has become crucial due to these challenges.

It indicates that to allow enhanced detachment to occur safely, these instruments have been designed, thus adding efficiency to the disassembly process. These include adjustability, ergonomics of design, options and materials used, compatibility with other items, safety attributes and simplicity of usage. These can reduce the physical stress towards the workers, reduce possibility of accident or mishaps, and also improve the overall productivity and effectiveness of the recycling process if focus is put on these elements.

The following is an introduction of some of the most important design aspects that should be considered while designing windscreen equipment aimed at the ELV sector. It shows how these equipment could aid in the industry's goals of sustainability and materials recovery specifically in the safer, efficient as well as environmentally sound dismantling of cars.

2.4.1 Adjustability

In some cases, the adjustability parameter is an essential feature to be considered while designing the windshield lifting tool because it considerably improves the accuracy and user friendliness of the tool. This must be possible in both the vertical plane and the horizontal plane so as to enable the windshield to reach the right position that is required. Horizontal movement allows the user to position the windshield at the appropriate tilt and provides a set of new opportunities for installation in connection with various car models.

Swing-bolt adjusters enable the changing of the angle of the trajectory of the windshield which moves horizontally so that it would be in line with the frame of the car. Not only that but angle adjustment is crucial, especially when it comes to installing the shelves successfully.

With such a large number of tilt degrees there is a possibility that the windshield is installed to be level with the car body and thus making sure that there are no gaps and the windshield is perfectly fits in place. Shall be easily movable and lockable so that it may be adjusted during assembly of the rest of the attachment. Thus, when one combines the movement in the vertical plane, in the horizontal plane and the angle of installation, then one sees that these types allow for the necessary flexibility and precision, which contributed to the ease of windshield installation and minimization of the risks of damage with a guarantee of optimal performance and maximum safety.

2.4.2 Ergonomics

The handle design of a windshield lifting tool is an essential consideration within a design process because it influences the user's experience and efficiency. The handle design should be the primary consideration. It must be ergonomically friendly to the natural adductor such that the risks of straining or over stressing during use are reduced particularly when the tool form must be used over an extensive period of time. For added comfort, and to ease injury on the hands due to constant pushing and pulling, the handle material should have a slip-resistance and could be cushioned. This is correspondingly true, because the users can be of different heights, and the instrument used should have height adjustment possibilities. Because this self-accommodation ensures that the user does not have to twist his or her body in each direction to use the product, this flexibility helps to minimize the likelihood of contracting musculoskeletal diseases.

An uncomfortable and ineffective tool could make the user adopt uncomfortable postures that are economically unsustainable for an extended period. It can rarely be optimally high or optimally low. It should also be adjusted by the user and therefore should allow for easy height adjustment and securely settle in the most appropriate height for any individual. It, therefore, increases both the safety and efficiency of the windshield lifting process over comfort not forgetting durability.

Angle adjustment of the windshield means the tilt can be adjusted to fit and match the shape of the slot or opening of the car, leaving no space and a perfect seal. This tilt adjustment should therefore be made in such a manner that it can be easily operated and then firmly locked into position when it has been brought to the desired angle which is achievable during installation. These features of the window regulator and the tilting of the windshield itself offer the necessary pliability and accuracy to guarantee a flawless installation of the windshield, thus excluding the possibility of damages, and ensuring that the equipped vehicle performs efficiently and safely.

2.4.3 Safety features

A windshield lifting tool must have conceptual considerations for protection measures to protect the user and the car. It will be seen that the locking mechanisms are a part of the security section that requires significant enhancements. These mechanisms ensure that the tool’s arms, grips and joints as well as connection points of its various working components are well-shut when the tool is in operation. It is very important to maintain stability so as to prevent some of the accidental slopes or movements that would make the windshield to drop or get out of place, and potentially harm or damage the occupants in the car or the windshield. Since the locking mechanism is to provide the user confidence that the tool will not move during the installation process, the lock engaging and releasing system should be simple to engage and release.

Therefore, besides such lock measures, an emergency production version must also be provided for the case of an emergency release. This feature allows the user to unlatch the windshield securely and quickly during an unexpected instability or when the tool used to install jams. In a situation where the user will require pressing the button hard in order to detach the windshield, then the chances are high that the user will employ excess force or endanger him/ herself. Another important application of this quick-release mechanism is to prevent accidents and ensure that neither the user of the windshield, the car, or the windshield itself gets harmed during an accident.

2.4.4 Ease of use

It is important that a windshield lifting tools design should be very usable so that most of the people could operate the tool with a lot of ease. The crucial element of such a design concept lies in the utilisation of accessibility controls. If the controls of the tool are easy to understand and there are understandable labels or names to the controls, then users should be able to understand more and use the tool with ease. This is done through having tough, switches, levers or buttons which are easily reachable and positioned reasonably. There are some features which can be helpful for the user during the operating process, and it is a requirement to make sure that every element of the operating process is explained optionally and every option is simple just like it is self-explanatory. It may require using such things as visual signals and feedback.

It should also be designed that the tool can easily be constructed and dismantled in merely a few steps. This means that assembling the instrument from its stowed state should be virtually effortless and a matter of seconds or at best minutes, and the components should click or fit into place cleanly without requiring locks or even latches to secure them in position. Apart from this efficiency of assembly and reduction of time needed, it also minimizes the risk of errors or mishaps. In order to ensure that the user does not get lost, confused or frustrated throughout a process that involves the product, the design should attempt to minimize the number of steps and at the same time make sure that each step is comprehensible. By stressing on basic configuration and dismantling processes, as well as clear control mechanisms, the tool gets optimized for ease of usage, which contributes to increased satisfaction ratings and efficiency among its users.

2.4.5 Durability and Materials

It is crucial when selecting the correct materials that are to be used in the construction of a windshield lifting tool to ensure that a long service time together with the best operating condition is provided. Since the tool is used to hold the windshield and by the time the car is complete, its usage might have been continued for quite a long time, the material used must be light to reduce hand fatigue and strong enough to support the windshield weight without bending or breaking. Therefore, suggested that for constructing the body and handle of the tool, high strength aluminium alloys are ideal since they offer the right combination of strength and weight. Additional weight can also be efficiently sloughed off with structural integrity maintained through the liberal use of carbon fibre composite components. If a windshield lifting bar may be used on widespread conditions, such as rain and humid conditions, then corrosion resistance is of the utmost importance.

This will not only facilitate in the construction of the tool, but it will also help to maximize the lifespan of the tool as the materials used are anti-rust and anti-corrosive, such as anodized aluminium or stainless steel. To add another layer of protection against the elements, you can also use protective anodized layer or powder coat. Not only do these treatments result in moisture resistance but also, they will also help in lengthening its operational time because further surface degradation is prevented. At the same time, depending on demanded conditions and loadings, the windscreen lifting tool shall offer rather stable work and a long useful life if the most durable, lightweight, and wear-resistant materials are selected and the assured high corrosion immunity is provided.

2.4.6 Compatibility

When defining the guards for a windshield lifting tool, not only its functionality must be considered, but also its possibilities of adapting the tool to any windshield size and any vehicle kind. Contemporary automobiles possess a system of different sizes and shapes of windshield so the tool under discussion should be constructed to adjust to many sizes and curvatures of the windshield. This can be achieved by including additional degrees of freedom that include flexible gripping attachment to hold the windscreen tightly and extenders that allow the tool to manipulate windscreen of any size. In addition, the fact that the tool is equipped with certain pivot points and articulating joints ensures that it will always be able to easily fit onto the windshield forms since there are no compromises here. Any wrong actions will likely result in a vehicle's windshield damage during its installation or removal.

The tool should also be compatible with different types of cars and must be able to interact with different car brands on the market. This needs to have infinite settings as it has to accommodate these varying degrees and places where the angles and mounting points of the various car types are sited. Whether it is a car, truck, or any other model, the variable base or mounting arm can ensure the meaningful tool's secure attachment to different car frames. This flexibility can be further increased by using quick interchange adapters or holders specifically made for automobiles, trucks, SUV's or other specialized forms of vehicles. Due to the near infinite variable and modular nature of the tool, specialists are also able to quickly modify it for optimal use with different automobiles, thus eliminating the need for most automobile specific tools. It was established that this broad compatibility is useful for technicians who desire a practical yet versatile tool that could be applied in a variety of scenarios, as it enhances efficacy and reduces the costs regarding effectiveness, in addition to broadening the functions of the tool.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The dismantling of ELVs is a crucial stage in the automobile recycling industry, aimed at extracting valuable materials and reducing environmental damage. A significant challenge in this process is the secure and efficient removal of car's windshield, which are commonly attached to the vehicle frame using strong adhesives. A solution has been developed to tackle these problems by designing a specific tool for lifting windshields when dismantling ELVs. The main goal of this device is to enhance the process of windshield removal, leading to enhanced safety, efficiency, and overall productivity in recycling operations. The windshield lifting tool employs advanced engineering principles and ergonomic design to provide a robust and efficient solution that surpasses the constraints of conventional methods. This section provides a comprehensive explanation of the design process that also includes the consideration of the workability of the product and efficiency in the current situation of the tool in the ELV industry. Moreover, the product's design goes through multiple evaluations to guarantee that the final design can achieve the desired outcomes and satisfy the market's aesthetic standards.

3.2 Flowchart

The flowchart as configure in **Figure 3.1** shows the overall workflow for both PSM 1 and PSM 2. For PSM 1, it will begin with define the problem from the project title. Study and do some research from journals and websites to determine the related study based on the project. Next, analyse the problem through the gathered information. After all, sketching design concept and selecting one suitable design that comply the parameters.

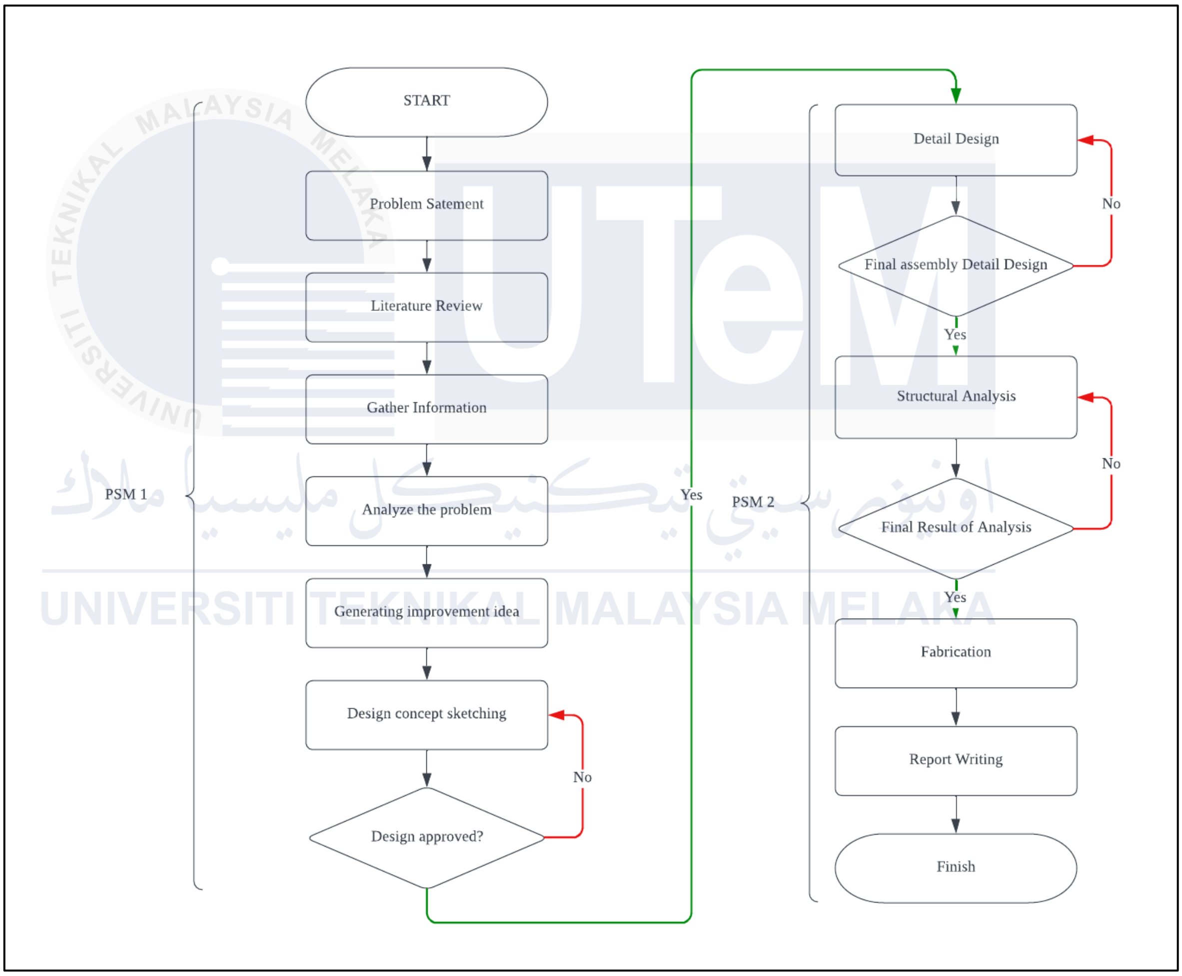

Figure 3.1 Flowchart

The flowchart above shows the overall workflow for both PSM 1 and PSM 2. For PSM 1, it will begin with define the problem from the project title. Study and do some research from journals and websites to determine the related study based on the project. Next, analyse the problem through the gathered information. After all, sketching design concept and selecting one suitable design that comply the parameters.

3.3 Gantt Chart

Table 3.1 and **Table 3.2** outlines the project timeline using Gantt charts for the two phases of the project, PSM 1 and PSM 2 to ensure systematic progress**.** Each task is plotted against a weekly timeline, distinguishing planned versus actual progress. This ensures accountability and efficient time management for project completion.

Table 3.1 Gantt chart for PSM 1

Gannt Chart for PSM 1																
No	Task Project	Plan / actual	Week													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	PSM title registration	Plan														
		Actual														
2	Project briefing	Plan														
		Actual														
3	Research about the title	Plan														
		Actual														
4	Introduction (Chapter1)	Plan														
		Actual														
5	Literature review (Chapter 2)	Plan														
		Actual														
6	Conceptual design brainstorming	Plan														
		Actual														
7	Methodology (Chapter 3)	Plan														
		Actual														
8	Design sketching	Plan														
		Actual														
9	Writing full report	Plan														
		Actual														
10	Submit draft to supervisor	Plan														
		Actual														
11	Project presentation	Plan														
		Actual														

Table 3.2 Gantt Chart for PSM 2

Gannt Chart for PSM 2																	
No	Task Project	Plan / actual	Week														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	CAD model development	Plan														
		Actual														
2	CAD model analysis	Plan														
		Actual														
3	Report writing (Chapter 4)	Plan														
		Actual														
4	Prototype printing	Plan														
		Actual														
5	Prototype assembly	Plan														
		Actual														
6	Report writing (Chapter 4)	Plan														
		Actual														
7	Report writing (Chapter 5)	Plan														
		Actual														
8	Submit draft to supervisor	Plan														
		Actual														
9	Full report finalization	Plan														
		Actual														
10	Project presentation	Plan														
		Actual														

3.4 Morphological Chart

Based on **Table 3.3**, the morphological chart shows the design concept for each component used in the conceptual design of windshield lifting tool. It will combine with different combinations to get three feasible combinations. Here, some potential components that might be part of the device have been identified.

Table 3.3 Morphological chart

Function	Solution 1	Solution 2	Solution 3
Type of suction cup	Vacuum	Heavy duty	
Number of cups	2	4	6
Wheel	Polyurethane wheels	Pneumatic wheels	Stainless steel wheel
Pillar	Rotate	Fix	
Pillar shape	Square	Cylinder	
Tool direction	From front	From side	

3.5 Conceptual Design

Based on the morphological chart above, it has been combining the function and get the three conceptual designs. The design will have different combinations and the design to be evaluated by using the weight sum method.

3.5.1 Conceptual Design 1

Figure 3.2 shows the first conceptual design is using vacuum for the suction cup and has four suction cups. It will use polyurethane wheels and the wheels have a locking option. The pillar shape indicated as A in the **Figure 3.2** is cylinder and can rotate. The tool direction will come from the side of the car.

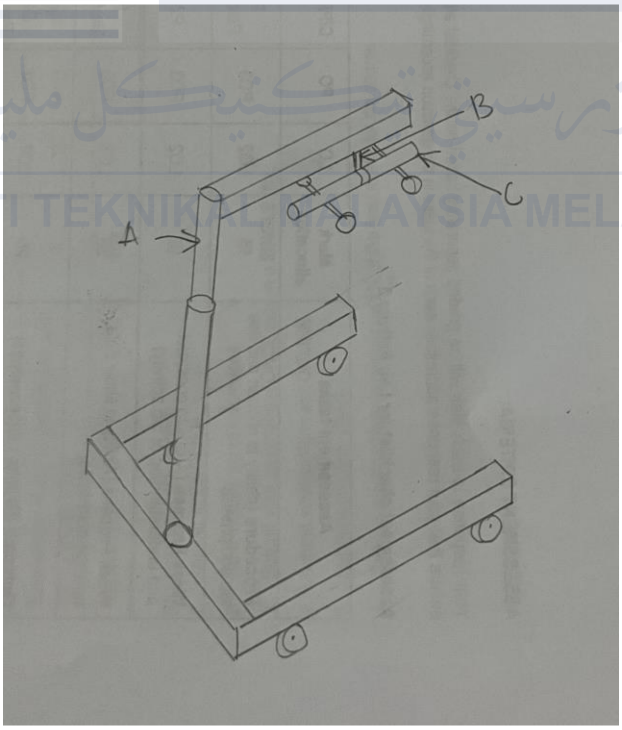

Figure 3.2 Sketching of Conceptual Design 1

3.5.2 Conceptual Design 2

Figure 3.3 shows the second conceptual design is using vacuum for the suction cup and has four suction cups. It will use pneumatic wheels and the wheels have a locking option. The pillar shape indicate as A is square and cannot be rotate. The tool direction will come from the front of the car.

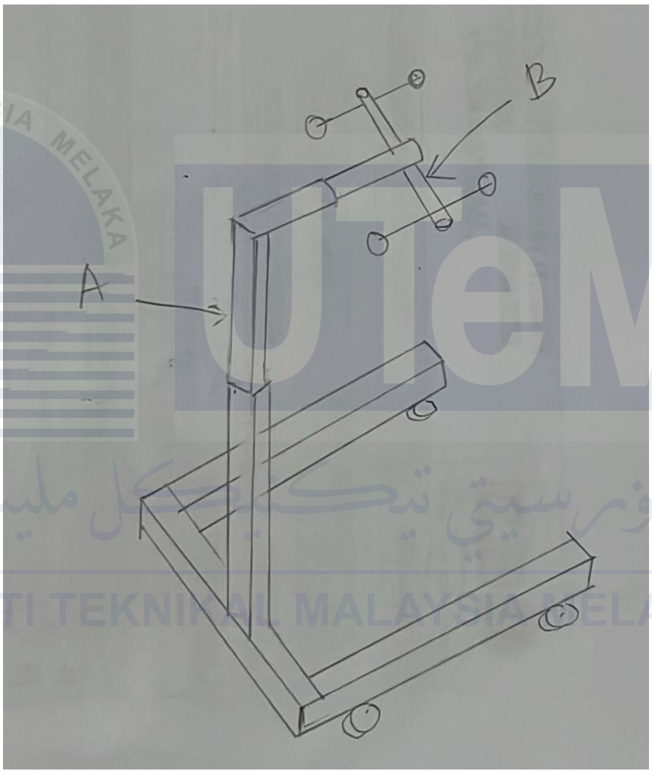

Figure 3.3 Sketching of Conceptual Design 2

3.5.3 Conceptual Design 3

Figure 3.4 shows the third conceptual design is using heavy duty for the suction cup and has six suction cups. It will use stainless steel wheels and the wheels do not have a locking option. The pillar shape indicate as B is cylinder and can rotate. The tool direction will come from the side of the car.

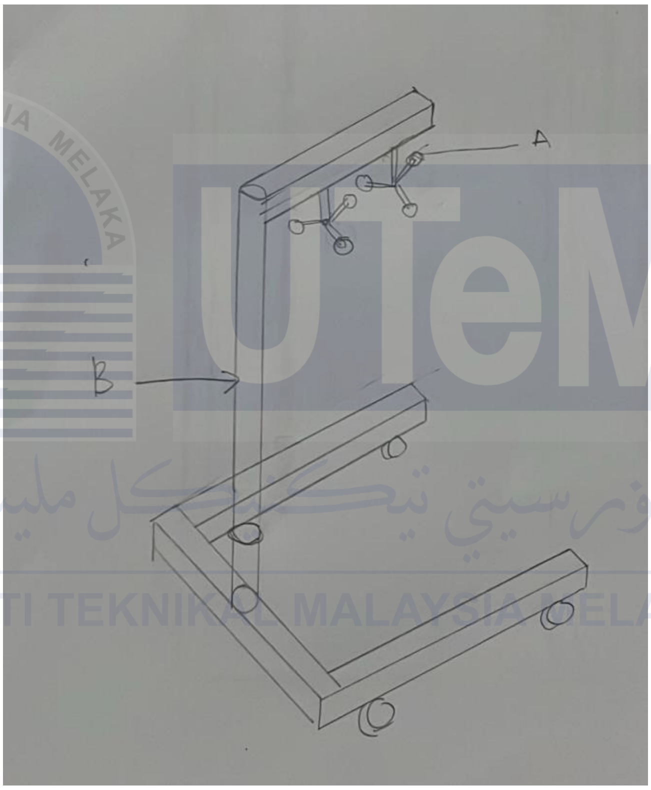

Figure 3.4 Sketching of Conceptual Design 2

3.6 Conceptual Design Selection

The weight sum method is used in the conceptual design selection process to methodically assess and contrast the three sketching designs. By giving weights to different criteria, rating each design according to several criteria, and adding up all of the weighted scores, the best design is found using this method. This structured approach ensures that all critical factors are considered and balanced against each other, leading to a well-informed decision. The result of weight sum methos is shown in **Table 3.4** below.

Weight sum method

Table 3.4 Weight sum method

	Weight factor	Concept 1		Concept 2		Concept 3	
		Score	Rating	Score	Rating	Score	Rating
Safety	0.25	8	2.00	7	1.75	9	2.25
Efficiency	0.20	7	1.40	8	1.60	6	1.20
Ease of use	0.15	7	1.05	6	0.90	8	1.20
Wheel lock mechanism	0.15	9	1.35	9	1.35	4	0.60
Durability	0.15	8	1.20	7	1.05	9	1.35
Cost effectiveness	0.10	8	0.80	7	0.70	6	0.60
Total	1.00	-	7.80	-	7.35	-	7.20
Ranking	-	-	1	-	2	-	3

The weight sum method result clearly identifies Conceptual Design 1 as the optimal choice with 7.80 point for the windshield lifting tool. This design's balanced performance across all evaluated criteria ensures it is well-suited for the ELV dismantling process, providing a reliable, efficient, and safe solution. The structured and transparent nature of the weight sum method ensures that the selection process is thorough and objective, leading to a well-informed decision.

3.7 CAD Drawing

The method of creating a computer-aided design (CAD) design for a windshield lifting tool using CATIA V5 is a detailed procedure that converts an initial sketch into a digital model. The project will benefit greatly from using CATIA V5, which is renowned for its strong design and engineering skills. The procedure began with conceptual drawing, whereby a preliminary design of the instrument was described on paper. This drawing consisted of vital elements, including raising arms, suction cups, the base of the tool, and other relevant parts.

After completing the conceptual drawing, the subsequent task required establishing the CAD environment in CATIA V5. This involved initiating a new project and setting up the workplace, which included selecting suitable units of measurement. Next, the procedure transitioned to the two-dimensional (2D) drawing stage, during which fundamental forms were sketched to provide the basis for each part of the windshield lifting tool. The tools built into the CATIA V5 design solution made it possible to define lines, arcs, and circles with precision, which were then embellished to include specifics such as apertures, slots, and mechanical joints, among others. These 2D structures were then marked with very detailed dimensions to ensure that all the corresponding features of components were proportioned and positioned correctly.

The next step involved transforming the design in the 2D form into three-dimensional (3D). CATIA V5 excelled at this stage as it supported the creation of 3D forms from 2D profiles by simply extruding them and modifying the 2D sketches in the x, y, and z planes to generate more complex structures. Each component was individually modelled with precision and subsequently assembled within the CATIA V5 environment. The assembly process in CATIA V5 allowed for seamless integration of the components, ensuring accurate alignment and connection of all parts. This process ensured that the tool's mechanical relationships and interactions were faithfully represented, with static relationships depicted through geometric and dimensional constraints to validate fixed specifications, while dynamic movements of parts were simulated to confirm their functionality.

During the detailing phase, the tool's layout was refined by adding geometric details such as fillets and chamfers. These additions contributed to achieving sharp and accurate edges that improved both the aesthetic and functional realism of the model. Additionally, material descriptions were assigned in CATIA V5, allowing users to visualize the final tool and understand how the selected materials might behave under operational conditions. This step was crucial for ensuring that the tool would meet performance requirements while being robust and reliable.

Finally, cast drawings at the essential exact scale were created based on the completed 3D assembly. These drawings, generated entirely in CATIA V5, ensured that all components were accurately dimensioned and ready for either prototyping or production purposes. This methodical approach resulted in a highly detailed and precise CAD replication of a windshield lifting tool, showcasing the comprehensive design and assembly capabilities of CATIA V5 as an advanced CAD software tool.

3.8 Structural Analysis

Strength analysis is an essential engineering procedure that involves evaluating the structural durability of a design to verify its ability to endure the applied loads and stresses during its anticipated lifetime. This method is crucial in guaranteeing the safety and dependability of diverse structural components. By using ANSYS software for this research, and beginning with a drawing from CATIA, the procedure combines complex simulation methods with precise design data to get precise and all-encompassing outcomes.

After the completion of the model in CATIA, it was exported from CATIA using a suitable format which is STEP. It was then loaded into ANSYS for further analysis. In ANSYS, the prepared CAD model was utilized for the subsequent step, known as FEA or strength analysis. The model included several sub-models limited to a specific number of components, thereby creating a mesh that allowed the program to analyse the structural response when subjected to various loads. An important aspect of the mesh was its quality, which directly impacted simulation accuracy since the mesh provided the necessary precision. Therefore, most efforts were aimed at increasing the density of the mesh around areas that were presumed to have higher von Mises stress values.

The next step involved defining the material properties and conditions of external actions the structure would have to withstand. ANSYS provided a comprehensive library of materials, which facilitated the creation of mechanical properties for the materials used in the structural design. The attributes included tensile strength, compression strength, tensile strength of stainless steel, and elasticity, among others. Depending on the presumed operational states, the loads applied to the structure were calculated, including static loads, dynamic loads, and conditions dependent on climatic factors, such as temperature changes.

Once the model, material attributes, and load conditions were defined, the analysis was performed in ANSYS. Through this process, the program determined the stresses, strains, and deformations of the structure when subjected to the specified loads. These solutions revealed critical areas where the material could easily deform, fail, or yield. More significantly, ANSYS provided detailed data such as stress analysis and stress distribution maps, deformation plots, and safety factor evaluations, enabling engineers to comprehensively understand the structural behaviour.

Furthermore, ANSYS included a feature that allowed the consideration of safety factors in the design process to account for variability in loads and materials. This safety consideration acted as an assurance, ensuring that the structure could handle variations, unforeseen incidents, or deviations from expected practices.

3.9 Prototype Development

The prototype development phase was a critical step in the realization of the designed tool for lifting windshields during ELV dismantling. To validate the conceptual design and CAD models, 3D printing technology was utilized to create a functional prototype. This method was chosen for its efficiency, precision, and ability to quickly produce physical models of complex geometries.

The process began with exporting the finalized CAD models, designed in CATIA, into STL files suitable for 3D printing. Each component, Base Frame, Vertical Column, Horizontal Arm, and Suction Mechanism (Lifting Head) was printed individually to ensure accuracy and modularity. A high-strength PLA material was selected for the prototype due to its durability, lightweight properties, and cost-effectiveness for testing purposes.

During 3D printing, particular attention was paid to the layer resolution and printing speed to ensure dimensional accuracy and surface finish. Support structures were used where necessary to maintain the integrity of overhangs and intricate features. After printing, the components were cleaned, assembled, and checked for dimensional consistency with the CAD models.

The assembled prototype provided a tangible representation of the tool and was instrumental in assessing its functionality and ergonomics. Preliminary tests demonstrated that the design effectively replicated the desired operations, such as stability, grip, and lifting capabilities. Additionally, the 3D-printed model allowed for iterative modifications, which enabled improvements to the design before proceeding to full-scale manufacturing.

Overall, 3D printing proved to be a highly efficient and cost-effective method for prototype development, bridging the gap between virtual design and physical implementation. The insights gained from this phase were crucial in refining the tool and ensuring its feasibility for real-world applications.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter discusses the findings of the study of a tool designed specifically for lifting windshields during the dismantling procedures of ELVs. Key stages in the research are reported and the outcomes achieved during these stages include the conceptual design phase, structural analysis and material selection process. It presents the results in depth and evaluates effects on results by the use of the developed tool to address the challenges of dismantling process.

More specifically, the findings show that the tool improved safety through a significant reduction in the risks of manual windshield removal. Moreover, it has made dismantling process simpler and more efficient, cut down time and labour requirements. The study also points out the tool's use of environmentally friendly materials and the possibility of promoting recycling. These outcomes emphasize the power of the proposed solution as the solution to pressing issues in the ELV dismantling industry.

4.2 CAD Model Development

The CAD drawing development phase was one of the most important steps of the design process where the drawings are made using the commercial software tools to final representation and assembling the ELV tool for lifting the windshields were done. This design was made in four separate parts known as Base Frame, Vertical Column, Horizontal

Arm, and Suction Mechanism, which again helped in better structuring, improved accuracy, and in assembling the design. The Base Frame is designed and developed through CATIA and is used as a solid base of the tool that can handle operational loads safely while remaining as light as possible. Its CAD drawings included features like mounting points and load distribution mechanisms every time it is in use, and it was then bolted to the full assembly using SolidWorks to ensure that it is compatible with the other components. The Vertical Column is another tool designed in CATIA and functions as the frame that links the Base Frame to the Horizontal Arm and gives the tool height and stability. It emphasized on perfect fit of connections since it dealt with structure stability and Its stability was tested during the SolidWorks assembly phase.

The Horizontal Arm which is aligned to the Vertical Column was modelled in CATIA to accommodate the Suction Mechanism or the Lifting Head of the windshield and enable accurate control of the windshield's position. CAD design incorporated controlled movement and weight distribution and CATIA simulations tested its functionality as well as stress capacity. Finally, the designed Suction Mechanism or Lifting Head in CATIA was developed to hold securely and lift the windshields throughout the operations. Integrating this component was done mainly with CATIA for assembly where the suction cups, connectors, and ability to lift as well as stability for the difference in sizes and shapes of the windscreen were tested. The use of CATIA for part design and assembly provided for an efficient development of the product as all the components were designed to fit and interconnect from the system. This holistic and systematic approach gave a rock-solid electronic reference model for subsequent processes of manufacturing and testing.

4.2.1 CAD Drawing of the Tools Components

The final assembly CAD drawing of the product is shown in **Figure 4.**1. By dividing the product into five parts, the design process became more manageable, allowing for precise CAD drawings of each component. This approach ensured that each part met its functional requirements while being seamlessly compatible with the others during assembly. Part by part CAD drawing is shown in **Figure 4.2** to **Figure 4.6**. Additionally, it allowed for targeted testing and improvements during the prototyping and final production stages, ultimately enhancing the overall reliability and performance of the windshield lifting tool.

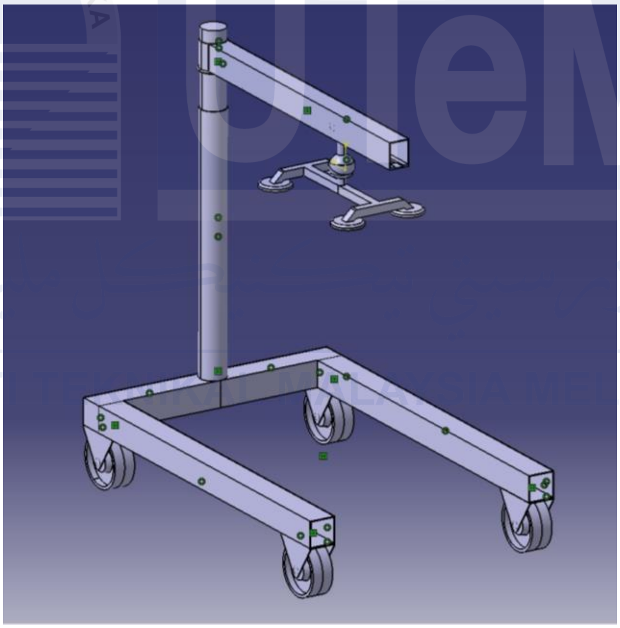

Figure 4.1 Final assembly of the tool

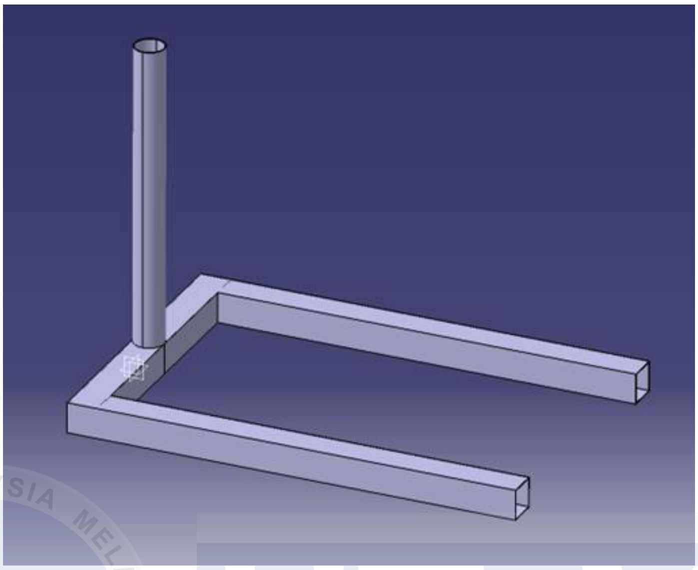

Figure 4.2 Base Structure

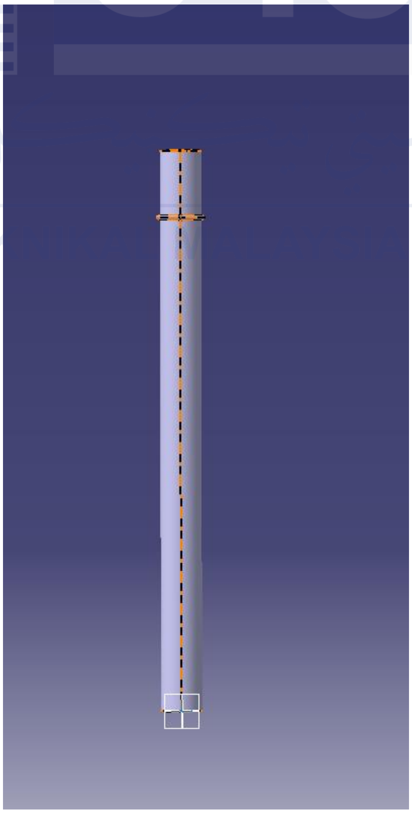

Figure 4.3 Vertical Column

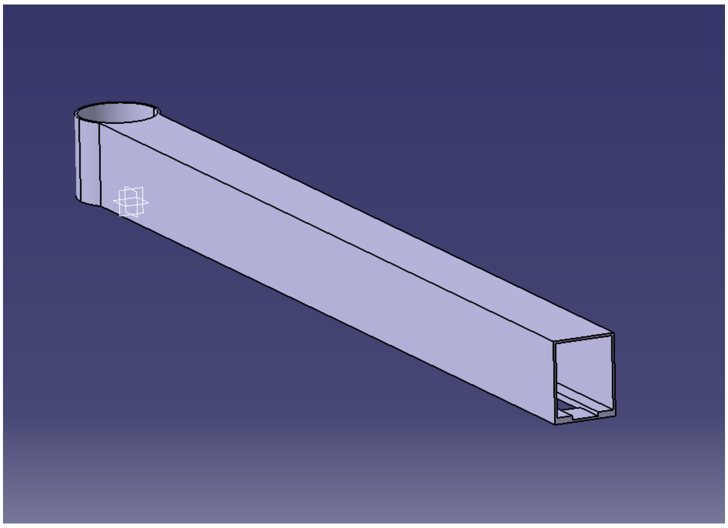

Figure 4.4 Vertical Arm

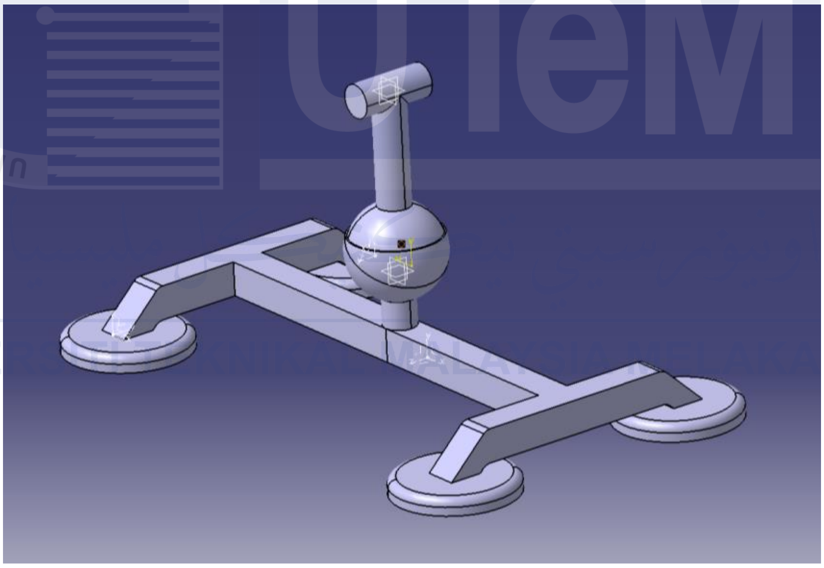

Figure 4.5 Suction Cup with Ball Joint

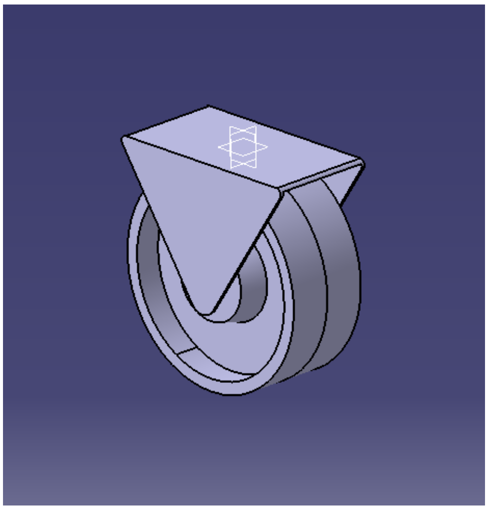

Figure 4.6 Wheel

4.3 Structural Analysis

ANSYS structural analysis is an intellectual process where the behaviour of a structure under placed loads, pressure, or conditions is determined. Some of the results seen during the analysis are total deformation, equivalent (von-Mises) stress, equivalent strain and the safety factor. Total deformation defines the displacements assumed by the structure when subjected to loads and can be used to determine regions of maximum flexibility or potential failure. The stress, using Von Mises criterion, checked whether the material will yield under the loads applied or not, which in turn checks that the design does not exceed safe stress limits. Equivalent strain determines the relative measure of deformation of the material which susceptible to ductility or failure in view of elongation or compression. These outputs together enable engineers to determine the level of safety and efficiency of different structures and designs.

4.3.1 Analysis of Total Deformation

For the minimum height configuration in **Figure 4.7**, the maximum deformation value is 1.6141 mm, occurring at the suction cup, which is the furthest point from the base and thus experiences the highest displacement. The average deformation across the tool is 0.13805 mm, indicating minimal overall movement. For the maximum height configuration in **Figure 4.8**, the maximum deformation value increases to 1.9692 mm, again concentrated at the suction cup. The average deformation in this configuration is 0.26927 mm, reflecting the greater displacement due to the extended height of the structure. In both configurations, the base frame and vertical column experience negligible deformation, confirming their structural rigidity. These results validate the design's ability to maintain structural integrity while minimizing deformation under operational conditions, ensuring reliable performance.

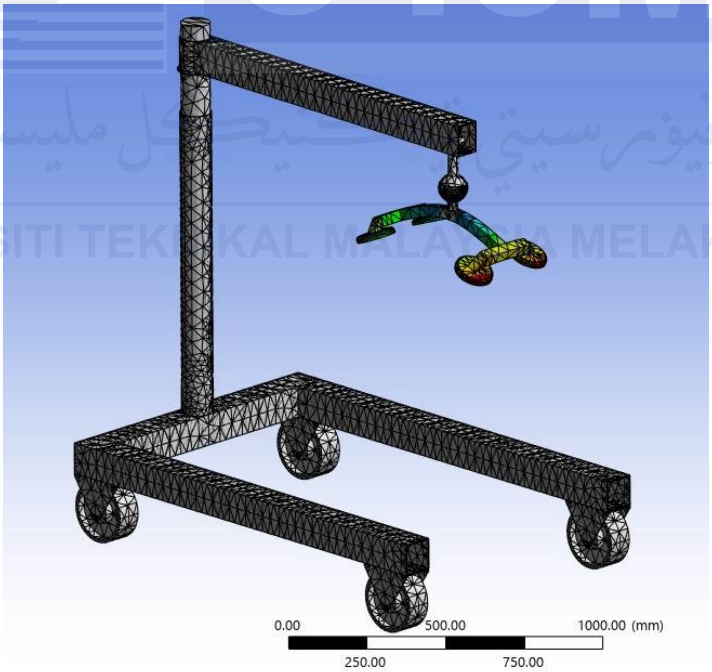

Figure 4.7 Total deformation for minimum height configuration

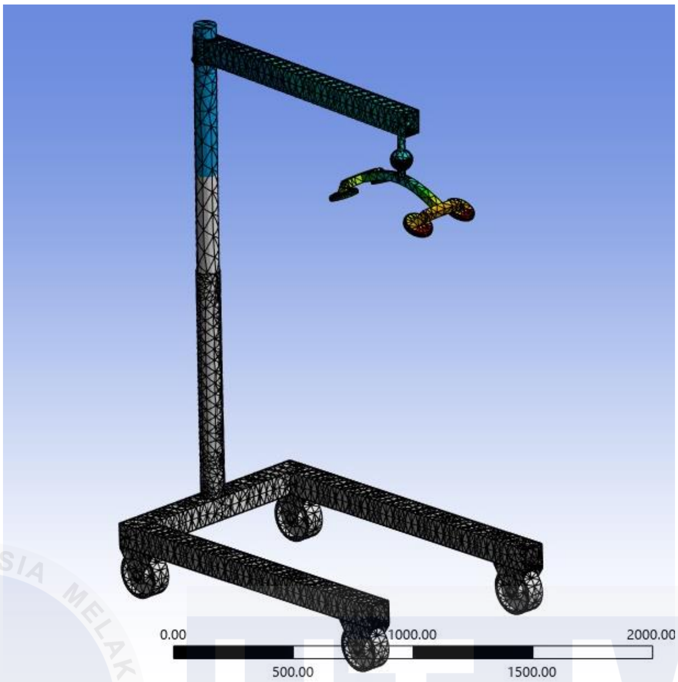

Figure 4.8 Total deformation for maximum height configuration

4.3.2 Analysis of Equivalent (von-Mises) Stress

The static structural analysis was conducted to assess the equivalent (von-Mises) stress distribution in the structure under the applied loading conditions. The results indicate that the maximum stress is 6.0468 MPa as shown in **Figure 4.9**, observed near the top of the vertical column close to the load attachment point, which is subjected to higher stresses due to the applied load and the structural configuration. In the **Figure 4.10**, the maximum stress is slightly reduced to 5.835 MPa, this occurs because of structural adjustments to minimum height for the tools. The minimum stress regions, consistently located at the base and other less critical components, confirm that the material utilization is efficient. Overall, the analysis demonstrates that the structure is capable of withstanding the applied loads, with stresses remaining within the permissible limits, while identifying critical stress points that can guide design optimization and material improvements.

Figure 4.9 Equivalent (von-Mises) stress for maximum height configuration

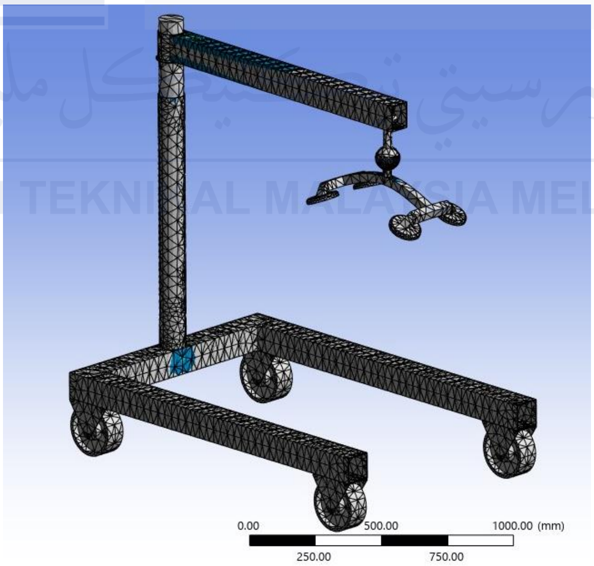

Figure 4.10 Equivalent (von-Mises) stress for minimum height configuration

4.3.3 Analysis of Equivalent Elastic Strain

The Equivalent Elastic Strain analysis was conducted to evaluate the deformation behaviour of the tool, consisting of a base frame, vertical column, horizontal arm, and suction cup, under applied load conditions at both its maximum and minimum height configurations. This analysis provides a scalar measure of the elastic strain across the tool, reflecting the strain energy density and identifying critical areas prone to deformation.

For the maximum height configuration as shown in **Figure 4.11**, the analysis reveals that the maximum equivalent elastic strain value is 0.00069371 mm/mm, occurring near critical regions, such as the connection between the horizontal arm and the suction cup. In this configuration, the strain concentration is more significant due to the extended structure, which increases stress in certain areas.

For the minimum height configuration as shown in **Figure 4.12** the maximum equivalent elastic strain value slightly increases to 0.00071769 mm/mm, also located near the connection between the horizontal arm and the suction cup. This configuration reduces the overall structural leverage, but the strain concentration remains localized in the same critical regions.

In both configurations, the minimal equivalent elastic strain values are observed in the base frame and vertical column, with values of 7.7079×10^{-5} mm/mm and 7.9744×10^{-5} mm/mm, respectively. These values confirm that the tool operates within the elastic deformation range of the material under the given load conditions, ensuring its structural integrity and reliability across varying height configurations. This analysis is crucial for validating the tool's performance and ensuring its safety in real-world operations.

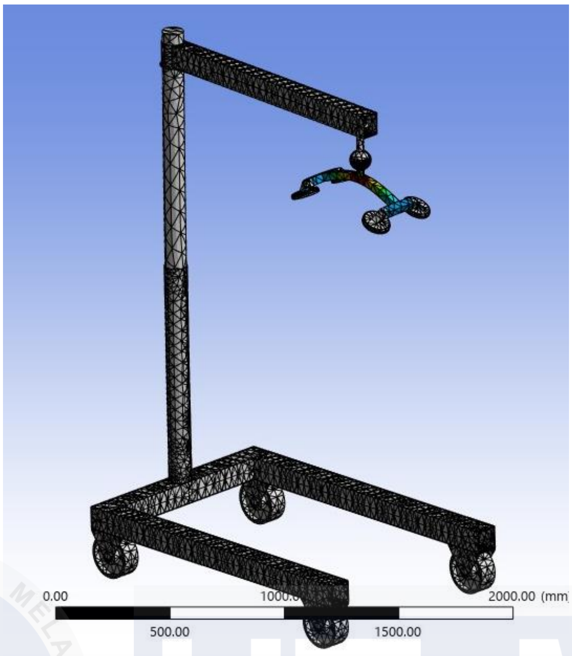

Figure 4.11 Equivalent elastic strain for maximum height Configuration

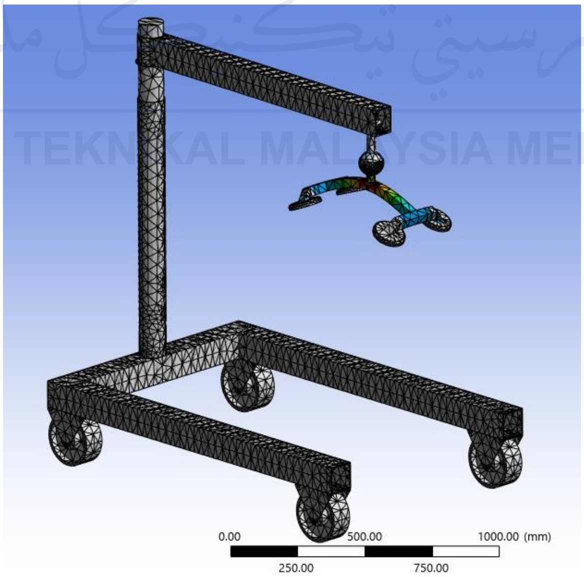

Figure 4.12 Equivalent elastic strain for minimum height Configuration

4.3.4 Safety of Factor

The Safety Factor analysis evaluates the structural design's capability to withstand applied loads without failure. A safety factor indicates the ratio of the material's strength to the applied stress, ensuring reliability under operational conditions. In this analysis, the results in the **Figure 4.13** and **Figure 4.14** show that the safety factor across the structure remains consistent either when using at minimum height or maximum height, with a maximum value of 15 and no regions falling below the minimum safety threshold. This uniform distribution of safety factor indicates that the structure is over-engineered for the given load conditions, providing a significant margin for unexpected load increases or material imperfections. Such analysis confirms the structural integrity and reliability of the design, ensuring it operates well within safe limits.

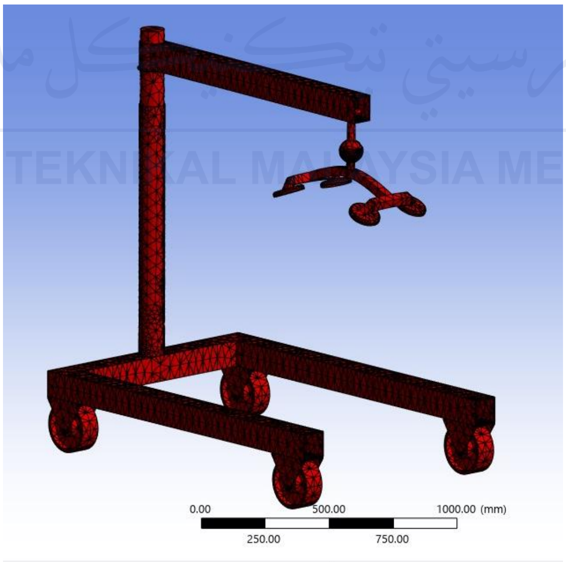

Figure 4.13 Safety factor for minimum height configuration

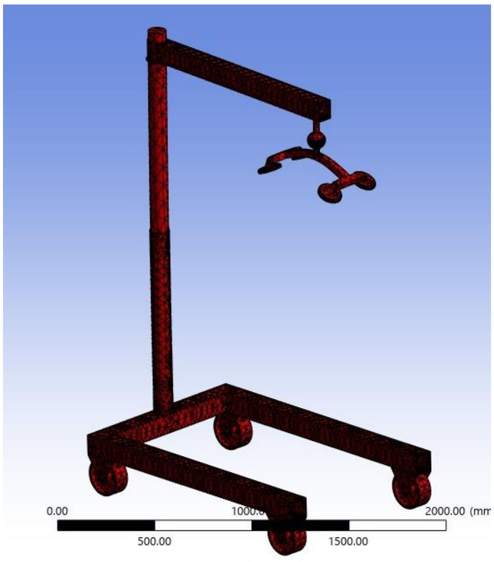

Figure 4.14 Safety factor for maximum high configuration

4.3.5 Prototype Development

The fabrication of a prototype for Conceptual Design 1 was successfully completed. **Figure 4.15** show the product after through all 3D printing process. The tool's functioning and performance were evaluated in controlled settings that replicated common ELV dismantling situations. These assessments verified its efficiency and identified potential areas for enhancement. The prototype demonstrated its capability to perform as intended, providing valuable insights for further refinements and optimization.

Figure 4.15 Prototype of the product

The CAD model received its final touches through CATIA V5 before beginning prototype development. The design model integrated every essential element of the windshield lifting tool through the base framework and vertical column combination with horizontal arm along with the suction system component. To facilitate initial testing and reduce resource usage, the model was scaled down to 1:6 of its actual size. The choice of a smaller scale replicated tool functions while reducing materials and shortening production duration. The final CAD model was exported to STL format which acts as a standard file type for 3D printing because it maintains pristine design accuracy while assuring widespread file compatibility.

The next step involved preparing for 3D printing. An FDM (Fused Deposition Modelling) printer met the research requirements because of its low-cost approach alongside dependable performance and its ability to produce detailed complex parts. PLA (Polylactic Acid) represented the selected printing material because it provides lightweight strength through durability and reduced environmental impact and economical production. Printed results became optimal through an exact layer height configuration of 0.2mm and infill density at 20% alongside support structure addition for overhanging parts or complex design features.

Each component of the tool was printed individually to ensure accuracy and modularity. The base frame was printed to provide a stable foundation capable of supporting the tool's weight and operational loads. The vertical column, designed to connect the base frame and horizontal arm, was printed to deliver structural integrity and height adjustment capability. The horizontal arm was printed with precision to support the suction mechanism and allow controlled movement for precise positioning of the windshield. Finally, the suction mechanism, a critical component for securely lifting the windshield, was printed to include suction cups and connectors capable of mimicking the functionality of the full-scale tool.

After printing, the components underwent a thorough post-processing stage. Support structures were carefully removed using pliers and fine tools and any rough edges were smoothed with sandpaper to ensure proper fitting and a clean finish. Dimensional accuracy was verified by comparing each component against the scaled-down CAD model, ensuring all parts met the required tolerances for assembly.

Once the components were cleaned and prepared, they were assembled into the complete prototype. The assembly process involved aligning and connecting the components based on the CAD design, ensuring proper fit and structural stability. The prototype was then subjected to functionality testing in a controlled environment that simulated real-world conditions. Key aspects tested included the stability of the base frame during operation, the structural integrity of the vertical column under load, the precision and flexibility of the horizontal arm's movement, and the suction mechanism's ability to securely lift and hold a scaled windshield model.

The prototype, scaled down to 1:6 and printed in PLA, proved effective in demonstrating the tool's functionality. Testing revealed that the base and vertical column provided adequate stability, the suction mechanism performed well under simulated load conditions, and the horizontal arm allowed for precise adjustments. These results validated the design while highlighting areas for potential improvement, such as optimizing the suction mechanism for better grip or refining the assembly process for greater ease.

Overall, the scaled-down prototype served as a critical step in the development process, enabling the team to test the tool's functionality and gather valuable feedback without the need for a full-scale model. This approach saved time and resources while ensuring that the design could meet operational requirements before moving on to full-scale production. By using 3D printing technology and PLA material, the team successfully demonstrated the feasibility of the windshield lifting tool and laid the groundwork for further refinement and real-world application.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The outcomes of this project successfully achieved the research objectives, demonstrating the effective design and development of a windshield lifting tool tailored for ELV dismantling. The first objective, which aimed to identify key parameters for the tool's design, was met through an extensive review of literature and analysis of essential features such as adjustability, ergonomics, safety, ease of use, durability, and compatibility. These parameters were incorporated into the design to address specific challenges in the ELV dismantling process.

The second objective, focusing on the design and analysis of the tool using CATIA V5 and ANSYS, was accomplished by creating detailed 2D and 3D models and performing FEA to evaluate structural integrity, stress distribution, and deformation under various operational conditions. The results confirmed the tool's robustness and reliability, with all critical performance indicators remaining within safe limits. Finally, the third objective of developing a prototype using 3D printing was achieved, allowing for practical testing and validation of the tool's functionality. The prototype demonstrated enhanced safety, efficiency, and operational performance, showcasing its potential to revolutionize the ELV dismantling process.

Collectively, the results align with the research objectives and underscore the project's significant contribution to enhancing safety, operational efficiency, and sustainability within the automotive recycling industry. By addressing the challenges associated with ELV dismantling, the project demonstrated how a carefully designed and tested windshield lifting tool can reduce worker strain, minimize risks of injury, and streamline the dismantling process. The tool's innovative features, such as ergonomic design, structural durability, and ease of use, ensure that it meets industry needs while improving overall productivity. Furthermore, its alignment with sustainability goals, through the promotion of recycling and resource conservation, highlights its potential to positively impact both the environment and the circular economy. The project's comprehensive approach from identifying key design parameters to validating the tool's functionality through simulation and prototyping which is provides a model for addressing similar challenges in other industries, emphasizing the broader applicability and importance of its outcomes.

5.2 Recommendations

This study presents an original concept and design of a windshield lifting tool targeting ELV workers and operations while focusing on performance, risk-related factors and environmental impact. To extend the utility of this tool, it is suggested to use the tool under actual operational conditions with the help of automotive recycling facilities. The details obtained from these tests would enable improvements to be made in the design and usability of these products. Furthermore, research into applying innovative materials, including lightweight composites, into the tool's design could enhance the product strength and portability.

Future versions may also consider the incorporation of robotic systems and such technologies as sensing systems for the precise dismantling of the structure. More emphasis should be made to the economic and environmental benefits of the tool which should entail a breakdown of the cost saving as well as cutting on material and emission costs. For the tool to be adopted widely, it would be very helpful to provide training for operators and, make the tool correspond to standards and policies. Finally, communicating the outcomes of the study in academic and trade journals might raise industry consciousness and promote the use of novel tools in automotive dismantling. These steps would make the research more relevant and useful as a contribution to the development of sustainable practice in the use of automobiles.

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