Properties of Recycled Aluminum A383 Alloy from End-of-Life Vehicle (ELV) Sources

Muhammad Syahmi Mohd Mazuki, Nizaroyani Saibani and Mohd Nizam Ab Rahman

***Abstract*—** End-of-life vehicles (ELVs) are one of the main contributors to the growing of complex solid waste. However, the material composition in ELVs holds significant potential for recycling, especially in recovering valuable materials such as aluminum alloys. Although the recycling process can reduce dependence on primary resources, a major challenge often encountered is the degradation in physical, mechanical and chemical properties and quality, mainly due to uncontrolled recycling procedures that can lead to the change of microstructural homogenity due to contamination and porosity when compared to primary aluminum alloys. This research aimed to evaluate and analyze the physical, mechanical and chemical properties of recycled aluminum alloy using recycled A383 alloy as the main sample that usually used in ELV component. This study involved several test method such as microstructural analysis using optical microscopy and scanning electron microscopy (SEM) along with elemental composition analysis of the material using Energy Dispersive X-ray Spectroscopy (EDX) , tensile testing using universal testing machine 100 kN to determine mechanical strength and corrosion test using the 3.5wt% NaCl salt immersion test to find out the accessiblity towards corrosion resistance. The findings show that recycled A383 alloy contains lower qualities and characteristics compared to A383 primary alloy. In terms of physical properties, secondary A383 alloy consists of 15.8% silicon, 2.3% copper, 0.2% magnesium, 1.2% zinc, 1.4% iron, 0.3% manganese, and 74.5% aluminum as the main component, whereas the primary A383 alloy contains 9.6–12% silicon, 1.5–3.5% copper, 0.3% magnesium, 1% zinc, 0.9% iron, 0.5% manganese, with the remain composition as aluminum. For mechanical properties, the secondary A383 alloy has an ultimate tensile strength of 141–182 MPa, a Young's modulus of 50.7–63.6 GPa, and a yield strength at 0.2% offset of 131–142 MPa. In contrast, the primary A383 alloy exhibits significantly higher mechanical properties, with an ultimate tensile strength of 310 MPa, a Young's modulus of 71 GPa, and a yield strength at 0.2% offset of 150 MPa. The corrosion rate of the secondary A383 alloy is high at 0.545 mm/year, whereas the primary A383 alloy has a lower corrosion rate of 0.083 mm/year over a 10-day immersion period. Although there is a slight reduction in properties compared to primary alloy, the recycled A383 aluminum alloy can still maintain the basic characteristics of metal materials such as tensile strength and yield strength and forms a protective oxide layer that slows down the corrosion rate over time. The microstructure also indicates potential for further improvement through heat treatment or better control of the remelting process. In conclusion, this study demonstrates that recycled aluminum alloy from ELVs remains suitable for use in non-critical applications such as internal components of electrical and electronic equipment, hardware, home decoration and in the automotive that does not impose to high burdens. This is important particularly where cost, sustainability, and metal waste reduction are priorities. This potential will supports industrial efforts toward sustainable development in line with circular economy principles

***Index Terms*—** End-life vehicles; Recycled Aluminum Alloy; Mechanical properties, Quality; Corrosion rate

I. INTRODUCTION

ELV refers to a vehicle that has reached the end of its service life and can no longer be used safely due to age, accidents or non-compliance with regulatory standards. ELV is also characterized as waste that can be disposed. In Malaysia, the lack of a comprehensive policy has caused a drastic increase in the number of ELV [1]. The absence of legislation regarding an ELV policy by the government has resulted in improper management of old and end-of-life vehicles [2]. ELVs also increase waste generation, as they are made up of many types of materials. However, over 80% of an ELV's total weight can actually be recycled (Petronijević et al. 2020), which helps prevent material wastage.

TABLE 1: Material composition in ELV

Material	Weightage (%)
Ferrous	65.4 – 71.0
Non-ferrous	7.0 – 10.0
Plastic	7.0 – 9.3
Rubber	4.0 – 5.6
Glass	2.9 – 3.0
Liquid	0.9 – 6.0
Battery	1.0 – 1.1
Polymer	1.0 – 1.1
Electric and electronic	0.4 – 1.0
Others	1.0 – 5.9

Source: [3]

Based on Table 1, the use of non-ferrous metals is the second most common in an ELV, with aluminum being the most widely used non-ferrous metal. It is the second most used metal after steel, and more aluminum is produced than all other non-ferrous metals combined [4]. Aluminum is now widely used due to its strong and excellent mechanical properties.

Aluminum, also known by its chemical symbol Al, is a silver-white metal that belongs to Group 13 on the periodic table. It is the most abundant metal in the Earth's crust, making up about 8.1% of its composition (Apblett 2005). Aluminum is also the second most widely used metal after steel, and more aluminum is produced than all other non-ferrous metals combined [4]. In 2018, global primary aluminum production

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was estimated at 64 million tonnes, compared to only 12 million tonnes produced through recycling methods [5], highlighting a significant gap between primary and secondary aluminum production due to the limited application of recycling practices.

Figure 1 refers to the use of aluminum alloy in vehicle frames, which is driven by its strong mechanical properties. Aluminum alloys offer high durability with minimal weight. The high strength-to-weight ratio of aluminum alloys allows them to be used in complex designs, providing the necessary structural integrity while remaining lightweight [6]. To produce a lightweight vehicle, the materials used must be light and have low density, while also possessing high durability for long-term use. The production of low-density vehicles contributes to energy savings, which in turn reduces fuel consumption. According to [7], lightweight materials are one of the technologies used to increase vehicle fuel efficiency by 6–8% for every 10% reduction in vehicle weight. Modern engine blocks made from aluminum typically contain 85% to 93% aluminum, combined with other elements such as silicon, magnesium, and copper to enhance strength and performance

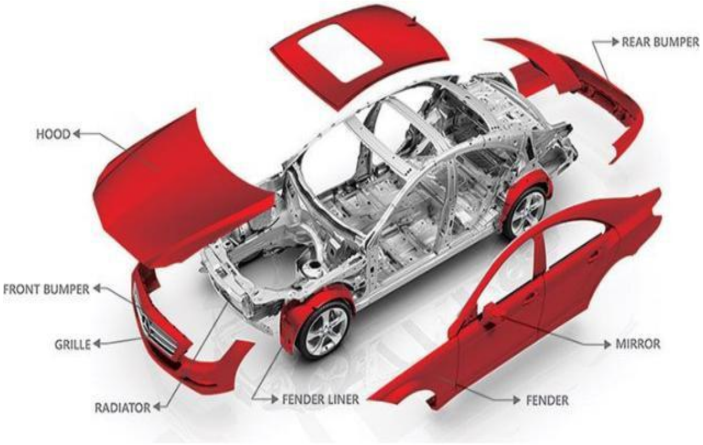

Fig.1: The use of aluminum alloy in the frame of lightweight vehicles.
Source: [8]

The aluminum alloy content of 25–50% in body structures such as panels, doors, and hoods serves to increase the density, thickness, and weight of these components to improve sound insulation performance [9]. In addition, the cylinder head is one of the heaviest components in the powertrain. Using 30–40% aluminum alloy can help reduce weight through conventional methods such as casting. The chassis and suspension systems form the main framework of a vehicle and have a significant impact on its total weight. Therefore, the use of 20–30% aluminum alloy in these systems can reduce the frame's weight, thereby decreasing the vehicle's overall weight.

II. METHODOLOGY

The main goal of this experimental work is to investigate how the recycling process affects the microstructure, composition, and performance of secondary aluminum alloys. By employing advanced analysis and testing techniques such as Scanning Electron Microscopy (SEM), Energy-Dispersive X-ray Spectroscopy (EDX), tensile testing, and corrosion conductivity analysis, this study aims to provide a comprehensive understanding of the materials properties. The findings will be compared with industry standards and pure aluminum to identify potential advantages, limitations, and areas for improvement in the recycling process. Ultimately, the results obtained will determine the suitability of secondary aluminum alloys for critical applications, offering valuable insights to advance sustainable practices in materials engineering and the automotive industry.

A383 alloy sample materials were obtained from the supplier from local recycling facility specializing in end-of-life vehicle (ELV) materials. The alloy was sourced from automotive components such as engine blocks and wheels, which contain a high aluminum content and are suitable for recycling. Upon receiving the samples from the supplier, they were in the form of irregular metal sheets with varying sizes and surface conditions. Most of the sheets displayed a dull silver color with visible signs of oxidation and the presence of surface contaminants such as grease and dirt, indicating prior usage and exposure to environmental conditions such as Figure 3.

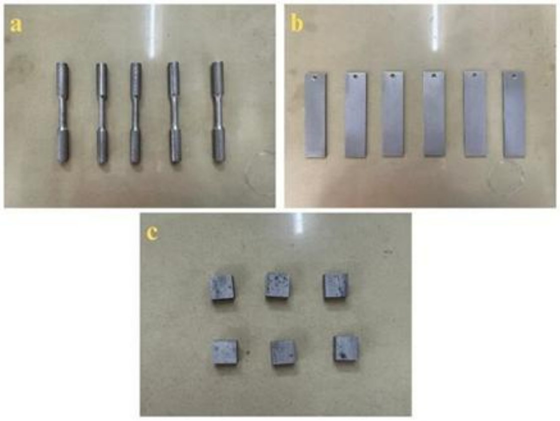

Fig.2: Sampel of alloy A383 for (a) tensile test (b) corrosion test (c) microstruture test.

In the material preparation process, the specimens must be cut and cleaned beforehand to obtain accurate, reliable, and representative results of the actual material properties. Surface cleaning is carried out using abrasive materials such as sandpaper to remove contaminated surfaces. Samples for microstructure testing and salt immersion testing will be ground using a machine as shown in Figure 2 (b) dan (c), while samples for tensile testing will be manually ground by hand .This process aims to eliminate oxide layers or external impurities resulting from the melting process during recycling.

Porosity is one of the critical parameters in evaluating the quality and performance of a material, as it can affect properties such as density, strength, ductility, and fatigue. Microstructural analysis is widely used to obtain an initial understanding of the material's quality, purity, and suitability. This analysis is employed to identify the presence of voids, impurities, and inconsistencies that may arise during the recycling process of aluminum alloys. The presence of porosity is determined using optical microscope olympus and scanning electron microscope (SEM) with Energy Dispersive X-ray Spectroscopy (EDX).

Tensile testing is a mechanical test used to measure the strength and ductility of a material by applying a uniaxial tensile force. This test provides important information about the material's ability to resist breaking under tension, yield strength, ultimate tensile strength (UTS), and elongation. The parameters measured such as ultimate tensile strength (UTS), Young's Modulus, yield strength and elongation. This test is conducted based on the internation standard which is American Society for Testing and Materials (ASTM E8). All of the parameters used as in Table 2.

TABLE II**:** Value of parameters used for tensile testing

Parameters	**Value**
Strain rate	$1.0 \times 10^{-3} s^{-1}$
Gauge length	$20\ cm$
Crosshead speed	$1.2\ cm/min$

Strain rate plays an important role in tensile testing as it influences the behavior of the material under load. At a low strain rate, the specimen undergoes plastic deformation over a longer period, leading to a reduction in yield strength and an increase in elongation. On the other hand, a high strain rate results in a stiffer material, with increased yield strength and tensile strength, although it remains ductile. This test is conducted using universal testing machine 100 kN as a precaution for expected load range which can ensures machine safety and accuracy.

The corrosion test was conducted to simulate atmospheric corrosion of metal under a thin liquid film. This experiment involved static immersion of the metal in an aqueous solution such as NaCl solution following the ASTM G31 standard, which involves the natural spontaneous corrosion mechanism. The test was carried out using a 3.5 wt% NaCl solution and then immersed at room temperature. To simulate an acidic atmospheric environment, the solution pH was adjusted to 3.5 by adding diluted hydrochloric acid. Five specimens were tested after 1, 2, 3, 4, and 5 days of immersion. Each specimen was gently washed with distilled water at the end of the test period to remove salt deposits from the material surface and then dried at a low temperature. Both initial and final weight are recorded to find out the weight loss due to corrosion. After that, microstructural analysis was performed using SEM

III. RESULT AND DISCUSSION

Aluminum alloy A383 is a type of cast aluminum alloy that belongs to the aluminum-silicon alloy group and is widely used in the automotive and electronics industries due to its excellent casting performance. Figure 9 shows the surface condition of the A383 sample under an optical microscope.

Eutectic silicon forms when silicon content exceeds its solubility in aluminum during solidification. It improves casting flowability and wear resistance, but if the particles are too large, sharp, or uneven, they can cause stress concentrations that initiate and propagate microcracks under tensile or impact loading. These coarse particles may also cause brittle fracture, reducing energy absorption and ductility.

The bright, angular-shaped phases in Figure 3 are intermetallic compounds rich in iron (e.g., Al-Fe-Si, Al-Fe-Mn), formed when excess iron combines with aluminum and silicon during solidification. These hard, brittle phases improve strength and wear resistance due to their strong bonds and ordered crystal structure, which resist atomic slip. However, in large or excessive amounts, they reduce ductility by limiting plastic deformation.

Fig: 3 A383 surface condition under optical microscope

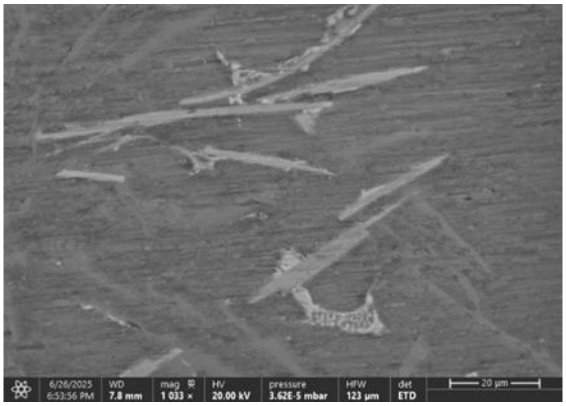

Fig: 4 Secondary A383 surface condition under SEM

Figure 10 shows the concentrated area on the material surface at 1033X magnification with a scale of 20 µm.. This area is used to analyze the material composition using EDX. Results as shown in Figure 4.

Fig.5: EDX count map

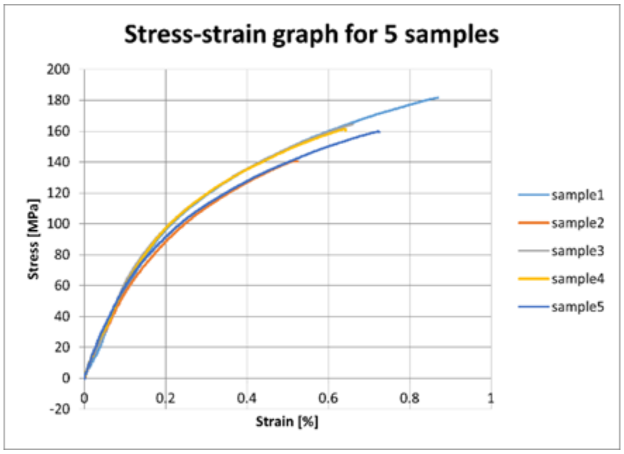

Fig.6: Stress-strain graph for 5 samples

Figure 5 shows the results of the EDX count map, revealing the overall distribution of various elements, with each color representing a specific element. Some elements are not evenly distributed, with overlapping and clustering observed in certain elements.

The high presence of silicon, such as eutectic silicon, is evident as the elemental composition analysis shows that Si is the second most abundant element after Al, the primary element, at 15.8 wt%. The presence of oxygen as the third most abundant element (4.3 wt%) can react with the metal to form an oxide layer, leading to porosity and internal cracking.

In tensile test, five sets of stress-strain graph data were obtained from five samples of A383 aluminum alloy sourced from the same origin showed as Figure 6 and recorded at Table 3. This was done to determine the maximum and minimum values as well as the range for the tensile strength of the A383 aluminum alloy. All five samples were subjected to a 20 N pre-load to ensure the samples were correctly positioned and taut in the grips. This was also to prevent any sudden movement or errors in the stress-strain graph due to system looseness.

TABLE III: ULTIMATE TENSILE STRENGTH VALUE FOR EACH

Sample A383	Ultimate tensile strength (MPa)
1	182
2	141
3	164
4	161
5	160

TABLE IV: TENSILE TEST DATA FOR EACH SAMPLE

Sample A383	Ultimate tensile strength (MPa)
1	182
2	141
3	164
4	161
5	160

The differences in ultimate tensile strength can be attributed to several key factors, particularly those related to the internal microstructure and porosity level of each sample. Porosity or gas bubbles within the material play a crucial role in determining a material's mechanical strength. Samples with higher porosity levels or larger pore sizes are less capable of withstanding large amounts of load. This is because pores act as stress concentration points, which facilitate the initiation and propagation of cracks when subjected to tensile loading. On the other hand, samples with low and fine porosity are able to bear higher loads, resulting in higher ultimate tensile strength due to a more homogeneous internal surface and a more efficient distribution of stress evenly throughout the structure.

Table 6 shows all the data gained from the tensile test. Young's Modulus also indicates how much a material can stretch elastically when subjected to a load. Based on Table 4, the Young's Modulus values for all five A383 samples range from 50.7 GPa to 63.6 GPa, where Sample 1 (62.7 GPa) and Sample 3 (63.6 GPa) recorded the highest values, indicating that these samples are stiffer in nature. Sample 2 recorded the lowest Young’s Modulus value, at 50.7 GPa, indicating that it has lower stiffness. Yield strength for the samples ranged between 131 MPa and 142 MPa. Sample 4 recorded the highest yield strength (142 MPa), indicating its ability to withstand higher loads before plastic deformation occurs.

IV. CONCLUSION

In conclusion, secondary aluminium alloys still hold great potential for use after recycling and it can function well in certain applications that do not require a very high level of performance or are not exposed to highly aggressive environments which can help reduce costs and protect the environment. However, the selection of a suitable application must take into account the performance limitations based on research data to ensure it is safe to use and suitable for long-term use such as internal components of electrical and electronic equipment , automotive parts that do not carry high loads, household hardware and home decor. This aligns with the circular economy approach and sustainable development, as emphasized in the Sustainable Development Goals (SDGs).

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