THE EFFECTS OF THE REINFORCEMENT OF ALUMINA AND RICE HUSK PARTICLES ON THE HYBRID RECYCLED ALUMINIUM AA7075 CHIPS COMPOSITE ON PHYSICAL, MECHANICAL AND MORPHOLOGICAL PROPERTIES

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In the Name of Allah, the Most Beneficent and the Most Merciful

This thesis is dedicated to:

My lovely parents;
Husband, Norhisham Samsudin
Father, Kamaruddin Zakaria and Mother, Noriza Mat Tahir
Father in law, Basri Abbas and Mother in law, Normah Abu Bakar

All my family members:
For their infinite love, patience and support.

Appreciate with love,
Thank you.

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ABSTRACT

Currently, agricultural waste derivatives have been incorporated with synthetic particles into a new generation of hybrid aluminium matrix composites (AMC) due to their excellent properties such as low density, accessibility, ability to reduce environmental pollution, and low production cost. This research investigates the effects of particle size of alumina (Al_2O_3) and composition of rice husk silica (RHA) as reinforcements of hybrid recycled aluminium chip composites using the cold compaction process. The AA7075 chip was reinforced with rice husk and alumina powder at range 0.5 -10.5 wt.%. Rice husk and alumina particles were 63 µm and 1.0 µm to 35.0 µm, respectively. Physically, AMC density increased with Al_2O_3 particle size. The highest density, porosity, and water absorption were found at 35.0 µm, with 2.5654 g cm^{-3}, 7.49%, and 3.18%, respectively; the lowest were found at 1.0 µm, with 2.3485 g cm^{-3}, 0.62%, and 0.24%. The density decreased by 3.0 wt.%, rose to 8.0 wt.%, then dropped. Density inversely affects porosity and water absorption. Mechanically, the maximum hardness and compression strength are 5.0 µm and 1.0 µm of Al_2O_3, respectively. Hardness and compression strength decreased with RHA content. At 0.5 wt.% RHA, hardness and compression strength were 111.99 HV and 174.62 MPa. At 10.5% RHA, hardness and compression strength are 53.70 HV and 65.58 MPa. As particle size increases, the distance between reinforcements increases, resulting in coarser grains. More RHA reduces pore formation and makes pores smaller and rounder. When RHA and Al_2O_3 are added, hybrid aluminium composites work better in aerospace, cars, marines, and electronics.

ABSTRAK

Pada masa ini, derivatif sisa pertanian telah digabungkan dengan zarah sintetik ke dalam komposit aluminium matriks hibrid (AMC) generasi baharu kerana sifatnya yang sangat baik seperti ketumpatan rendah, kebolehcapaian, keupayaan untuk mengurangkan pencemaran alam sekitar dan kos pengeluaran yang rendah. Penyelidikan ini menyiasat kesan saiz zarah alumina (Al_2O_3) dan komposisi silika sekam padi (RHA) sebagai pengukuhan komposit cip aluminium kitar semula hibrid menggunakan proses pemadatan sejuk. Cip AA7075 diperkukuh dengan sekam padi dan serbuk alumina pada julat 0.5 -10.5 wt.%. Sekam padi dan zarah alumina ialah 63 µm dan 1.0 hingga 35.0 µm, masing-masing. Secara fizikal, ketumpatan AMC meningkat dengan saiz zarah Al_2O_3. Ketumpatan, keliangan, dan penyerapan air tertinggi didapati pada 35.0 µm, dengan 2.5654 g cm^{-3}, 7.49%, dan 3.18%, masing-masing; yang terendah didapati pada 1.0 µm, dengan 2.3485 g cm^{-3}, 0.62%, dan 0.24%. Ketumpatan menurun sebanyak 3.0 wt.%, meningkat kepada 8.0 wt.%, kemudian menurun. Ketumpatan secara songsang mempengaruhi keliangan dan penyerapan air. Secara mekanikal, kekerasan maksimum dan kekuatan mampatan ialah 5.0 µm dan 1.0 µm Al_2O_3, masing-masing. Kekerasan dan kekuatan mampatan berkurangan dengan kandungan RHA. Pada 0.5 wt.% RHA, kekerasan dan kekuatan mampatan ialah 111.99 HV dan 174.62 MPa. Pada 10.5% RHA, kekerasan dan kekuatan mampatan ialah 53.70 HV dan 65.58 MPa. Apabila saiz zarah bertambah, jarak antara tetulang bertambah, menghasilkan butiran yang lebih kasar. Lebih banyak RHA mengurangkan pembentukan liang dan menjadikan liang lebih kecil dan lebih bulat. Apabila RHA dan Al_2O_3 ditambah, komposit aluminium hibrid berfungsi lebih baik dalam aeroangkasa, kereta, marin dan elektronik.

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LIST OF SYMBOLS AND ABBREVIATIONS

AMC	-	Aluminium Matrix composite
Al_2O_3	-	Alumina / Aluminium Oxide
Al_4C_3	-	Aluminium Carbide
Al	-	Aluminium
AlN	-	Aluminium Nitride
ASTM	-	American Society for Testing and Material
B_4C	-	Boron Carbide
BN	-	Boron Nitride
BHN	-	Brinell Hardness Number
CMC	-	Ceramic Matrix Composites
Cr	-	Chromium
Cu	-	Copper
CeO_2	-	Ceric Oxide
EDX/EDS	-	X-ray Energy Dispersive Spectroscopy
Fe	-	Iron
FEC	-	Forming Extrusion Cutting
GSA	-	Groundnut Shell Ash
HBN	-	Hard Boron Nitride
HV	-	Vickers Pyramid Number for hardness testing
HAMC	-	Hybrid Aluminium Matrix Composite
MMC	-	Metal Matrix Composites
Mn	-	Manganese
MoS_2	-	Molybdenum Sulfide
Mg	-	Magnesium
OM	-	Optical Microscope
PMC	-	Polymer Matrix composite
PM	-	Powder Metallurgy

RHA	-	Rice Husk Ash
RH	-	Rice husk
SiC	-	Silicon Carbide
SiO_2	-	Silicon Dioxide
Si_3N_4	-	Silicon Nitride
SEM	-	Scanning Electron Microscope
Ti	-	Titanium
TiC	-	Titanium Carbide
TiB_2	-	Titanium Diboride
TlN	-	Thallium Nitride
UTM	-	Universal Testing Machine
UTS	-	Ultimate Tensile Strength
WC	-	Tungsten Carbide
Zn	-	Zinc
ZrC	-	Zirconium Carbide

LIST OF PUBLICATIONS

Journals:

i. Kamaruddin, N.A., Nasir, N.F., N.A., Roslan, M. F., & Joharudin, N. F. M. Physical properties of rice husk silica / alumina reinforced aluminium alloy matrix composite produced by cold compaction process. *Materials Science and Engineering*. (Acceptance on 27th June 2022)

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CHAPTER 1

INTRODUCTION

1.1 Research Background

A composite is a mixture of two or more materials with different mechanical and physical properties, one as a matrix and the other as a reinforcement. One of unique classes of composites is aluminium matrix composite (AMCs). There are two categories of aluminium: primary aluminium and secondary aluminium. Primary aluminium is mined from ore, while secondary aluminium results from scrap metal.

Based on the International Aluminium Institute data, global primary aluminium output increased by 176,000 tonnes, or 3.10% per month in July 2022. China produced the highest amount of aluminium, 3.468 million tonnes, followed by Asia with 382,000 tonnes, and Oceania 153,000 tonnes (Ganguly, 2022). Aluminium hybrid composites reinforced with ceramics particles are in high demand, with applications used in nuclear power plants, automotive, aerospace, thermal management, and sports. This is due their low weight, excellent corrosion resistance, higher thermal conductivity, and wear resistance.

Selecting the proper fabrication method, process parameters, and reinforcing type aid in determining the required characteristics of manufactured AMCs. According to Hariharasakthiansudhan, P., and Jose, S. (2017) showed that the use of dual particle size reinforcement enhanced composites' tribological and mechanical properties. The result of ultimate tensile strength is 72.3 MPa, yield strength of 148 MPa, compression strength of 253 MPa and the hardness of the composites was dominated by single reinforcement. The strengthening mechanism of the dual reinforcement in the composites is the dislocation density due to proper bonding between the presence of Si_3N_4 nanoparticles and hard Al_2O_3 particles in the matrix. AMCs frequently use ceramic particles such as Al_2O_3, SiO_2, SiC, and TiO_2 as synthetic reinforcement. The properties of this reinforcement is, high wear resistance, high-temperature properties, low pressure sintered to full density in the air, thermal stability, high chemical resistance, and high hardness. According to Zamani et al. (2020), the hardness, tensile strength, and compressive strength of an Al_2O_3 nanoparticle reinforced aluminium matrix composite produced by powder metallurgy increase with increasing Al_2O_3 volume.

In addition, natural resources and industrial waste, such as rice husk ash, red mud, fly ash, coconut shell ash, and sugar bagasse ash, have been utilized in AMC as reinforcement. Rice husk contains 85 to 87% silica compared to other biomass fuels, representing a high level of porosity and having lower densities than other technical ceramics (such as boron carbide, alumina), low weight, and a large exterior surface area, thereby reducing the cost of aluminium products. RHA's primary component is amorphous silica, which is utilised in the production of silica gels, the synthesis of activated carbon and silica, silicon chips, the production of lightweight construction materials and insulation, catalyst, and other applications (Pode, 2016; Tiwari & Pradhan, 2017). In an investigation of the Al7075/ RHA/ Mica composite by squeeze casting, Sathiesh Kumar (2021) found that as RHA content increased, hardness increased, impact energy decreased, and tensile strength increased up to 10%, then decreased to 15%.

This study examines the physical, mechanical and morphological properties of the hybrid AMCs made with agro-waste (RHA) products as a supplement to the synthetic reinforcement (Al_2O_3) in the cold-compacted process AMC. The advantages of this method compared to the melting method are low processing temperature to prevent undesirable phases between matrix and reinforcement, low cost, the ability to shape the powder directly into its final parts, the ability to create complex-shaped parts, and the reduction of machining time (Abbas Gohar et al., 2018; Kumarasamy et al., 2017; Liu et al., 2016; RaviKumar et al., 2018b). Previous research has demonstrated that the cold compaction method improves AMC's mechanical and physical properties. According to Zamani et al. (2021), cold compaction provides uniform distribution and strong bonding between the matrix and reinforcement, with no holes. Consequently, it generates AMCs with excellent mechanical properties. In addition, N.F. Mohd Joharuddin et al. (2019) discovered that RHA amorphous silica filled the voids and covered the pores in the AA7075 aluminium chips to produce a smooth surface on the sample. Sherafat Z. et al. (2009) investigated the fabrication of Al7075/Al, a two-phase material, by recycling Al7075 alloy chips via powder metallurgy. Ab Kadir M.I. et al. (2017) analyzed the microstructural and mechanical properties of an aluminium chip strengthened with Al powder using the cold compact technique. Researchers also proved that Al 7075 reinforced with alumina produces better mechanical properties than Al 6061 reinforced with SiC (Krishnan et al., 2019).

1.2 Problem Statement

The material involved in this research is aluminium AA7075 as a matrix, with alumina and rice husk ash as reinforcement. The properties of aluminium are ductile, high strength-to-weight ratio, thermal conductivity and attractive natural finish. However, aluminium shows very low strain hardening in plastic deformation and performs poorly in fretting, wear, impact, and energy absorption. Aluminium possesses a low melting point (660°C) and density (2.70g/cm^3) (Ashkenazi, 2019). Thus, the combination of aluminium's superior ductility and ceramic reinforcement will produce an advanced material for applications requiring wear resistance, high strength, and hardness. Reinforcement may consist of fibres or particles. This is because such reinforcement will control the microstructures, size and distribution of constituents, tribology, and mechanical properties over percentage by weight (Zaiemyekeh et al., 2019).

Synthetic reinforcement such as Al_2O_3, TiO_2, SiC, SiO_2 and graphite are commonly used in AMCs. Alumina can prevent the formation of undesirable phases and reactions with the matrix due to the fact that aluminium is highly reactive with atmospheric oxygen. This is because alumina in a pure aluminium matrix is regarded as the optimal dispersion with no chemical reaction. In addition, oxide coatings such as Al_2O_3 protect the fabrication of composites, thereby preventing the formation of the Al_4C_3 phase (aluminium carbide needle phase), which is detrimental to the corrosion resistance and mechanical properties of AMCs (Bodunrin et al., 2015). Unfortunately, the high manufacturing costs associated with synthetic reinforcement limit the use of AMCs in automotive and other applications. Utilizing organic resources and industrial waste is one way to reduce production expenses. Rice husk ash is an agricultural byproduct that also serves as a mineral additive. The primary component of RHA is amorphous silica and contains high silica compared to the other waste, which is utilized in producing silica gels, synthesizing activated carbon and silica, silicon chips, lightweight construction materials and insulation (Pode, 2016). In addition, rice husk is considered a waste product and is used as a combustion material in rice mills and factories' boilers (Kannan, 2018).

Previous researchers have reported a lack of research on combining two reinforcements in AMC, such as alumina and RHA. Therefore, the effects of reinforcing hybrid AA7075 aluminium chips with alumina and rice husk particles were studied to enhance the physical, mechanical, and morphological properties of AMC. This is anticipated to contribute to the long-term viability of primary aluminium resources for recycling.

1.3 Objectives of the Study

The purpose of this study is to:

(i) To investigate the effects of 2 wt.% of alumina in various particle sizes as reinforcement on the physical, mechanical and morphological properties of hybrid recycled aluminium chips.

(ii) To investigate the effects of rice husk silica in different weight percentages on the physical, mechanical and morphological properties of hybrid recycled aluminium chips.

1.4 Research Scopes

The following is the scope of this research:

1. Recycled AA7075 aluminium chips as a matrix, and it was reinforced with alumina particles and rice husk particles.
2. Preparation of the specimen hybrid aluminium composite reinforced with different sizes of 2 wt. % alumina (1.0µm, 5.0 µm and 35.0 µm) and different weights percentage of rice husk ash (0.5%, 3.0%, 5.5%, 8.0% and 10.5%).
3. The fabrication process of aluminium chip reinforced with alumina particles and rice husk ash (silica) in various percentage and particle sizes was

performed by using ball milling process. The fabrication of AA7075/ RHA /Al_2O_3 samples were performed under cold compaction process.

4. The effect of rice husk ash and alumina on the aluminium physical properties was determined through density following ASTM B328, while porosity and water absorption by the ASTM B962-17 standard.
5. The hardness and compression properties of AMCs were evaluated using the Vickers Hardness and Compression Test followed by the ASTM E384 and ASTM E9 standards, respectively.
6. The morphology properties were analysed under Optical Microscope and Scanning Electron Microscope.

1.5 Significant of Study

The selection of fabrication process and raw materials is crucial to achieving a successful outcome when fabricating RHA/Al_2O_3-reinforced hybrid recycled aluminium AA7075 matrix composites. There are a few hypotheses for this research:

i. The cold compaction method is superior to the melting process for the following reasons: low processing temperature to prevent undesired phases between matrix and reinforcement, the ability to shape the powder directly into its finished parts, the ability to create complex-shaped components, and a reduction in machining time.

ii. The different particle sizes of alumina as a hardening phase in aluminium chip recycling can improve AMC's properties due to the alumina's oxides content.

iii. Reinforcement Rice husk ash particles can increase a sample's hardness and compressive strength due to the high silica content of rice husk ash.

iv. Increasing the reinforcement provides an average sample density with reduced porosity and water absorption.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A growing number of researchers are examining the cycling process of aluminium chips due to their commercial value, excellent properties, and potential applications in manufacturing technologies for aircraft, automobiles, and marine vessels. As a result, manufacturer was able to achieve greater benefits from this material, including enhanced performance, cost savings, and environmental advantages.

2.2 Aluminium Alloy

Aluminum alloys are made from scrap aluminium. Compared to industrial primary aluminium, scrap aluminium alloy has a lower melting temperature, a shorter melting time, a lower metal burning loss, and lower energy consumption. During the alloy composition adjustment phase, less metal is added to the scrap aluminium alloy while the alloy composition distribution becomes more uniform and optimises the microstructure. Additionally, the energy consumption per tonne of recycled aluminium production is only about 3–5% of that of primary aluminium production, reducing production costs and decreasing carbon dioxide and sulphur oxide emissions during manufacturing. It contributes to the conservation of resources and protecting the environment (Zhou et al., 2021).

Both cast and wrought aluminium alloys are types of aluminium alloy. One can be fabricated from solid metals, while the other is constructed from molten alloys poured into a mould. Based on their strengthening working conditions, heat-treatable and non-heat-treatable aluminium alloys can be categorised. The Aluminium

Association Inc. uses a four-digit system to classify wrought alloys into nine different series, each with a unique combination of alloying additions. First-digit alloys (Xxxx) are primary components, while second-digit alloys (xXxx) are modifications. An alloy can be determined by the last two numerals (xxXX) of the serial number. A wide range of applications is possible because of the wide range of material qualities (Georgantzia et al., 2021). Table 2.1 describes details about the properties of aluminium series alloys.

Al 7xxx alloys, also known as aluminium-zinc alloys, are anticipated to contain a maximum amount of zinc between 5.1 and 6.1 % (Imran & Khan, 2019). In addition, Al 7075 has superior quality and tensile strength, making it useful for aerospace and automobile components. Furthermore, Al 7075 has superior mechanical properties to Al 6061. In addition, Al 7075 is superior to Al 2024 and Al 6061 series due to its superior heat treatability and response to ageing (RaviKumar et al., 2018b).

Table 2.1: Properties of aluminium series alloy (Zhang, Jinliang et al., 2019).

Series	**Types**	**Elements**	**Performance**
1xxx	non-heat-treatable	Pure Al (>99.00%)	Low strength, good corrosion resistance and conductivity, easy processing
2xxx	heat treatable	Al-Cu/AL-Cu-Mg	Hard aluminium alloy, high-strength, good heat resistance, poor corrosion resistance
3xxx	non-heat-treatable	Al-Mn	Antirust aluminium alloy, low strength, cold-working-hardening, good plasticity and weldability
4xxx	non-heat-treatable	Al-Si	High silicon, low melting point, good weldability, good heat and wear resistance
5xxx	non-heat-treatable	Al-Mg	High magnesium, good corrosion resistance and weldability
6xxx	heat treatable	Al-Mg-Si	Medium strength, good formability, weldability and machinability
7xxx	heat treatable	Al-Zn-Mg	Very high strength, cannot be welded, poor corrosion resistance
8xxx	-	Other elements	-
9xxx	-	Spare alloys	-
9xxx	-	Spare alloys	-

2.2.1 AA7075 Aluminium

Al 7075 is the most widely utilised grade for fabricating single and hybrid reinforced composites. The main alloying element in this grade is Zinc. The composition of Al 7075, as shown in Table 2.2 which are Cr (0.18 – 0.28 %), Ti (0.2 %), Mn (0.3 %), Si (0.4 %), Fe (0.5 %), Cu (1.2 – 1.6 %), Mg (2.1-2.5%), and Zn (5.6 – 6.1 %). It has superior workability, corrosion resistance, thermal conductivity, strength, low density, improved wear and erosion resistance, and stiffness and is inexpensive. In addition, it improves hardness, dislocation density, reinforcement dispersion, and interphase bonding (Sharma & Mishra, 2019; Wu et al., 2014).

Table 2.2: Chemical composition of Al 7075 (Imran & Khan, 2019).

Composition	Zn	Si	Fe	Ti	Cu	Mn	Mg	Cr	other	Bal
Percentage	5.1-6.1	0.4	0.5	0.2	1.2-2.0	0.3	2.1-2.9	0.18-0.28	0.65	Al

2.2.2 Physical, Mechanical and Morphological Properties

Aluminum 7075 has the physical properties of being a lightweight metal with a density of 2.81g/cm3. This type is also advantageous in high-pressure situations. The copper content of 7075 aluminium increases its susceptibility to corrosion. However, this sacrifice is required to create a material that is both durable and workable.

The modulus of elasticity and shear modulus measure a material's deformation resistance. 7075 aluminum's elasticity modulus is 71.7 GPa (10,400 ksi) and its shear modulus is 26.9 GPa (3900 ksi). This alloy is strong and resists deformation well, making it ideal for tough-yet-light applications. Yield strength is the maximum stress (or force) that won't permanently deform a material. 7075 aluminium alloy has a tensile yield strength of 503 MPa (83,000 psi), meaning it takes 503 MPa of stress to deform it. This value shows the benefit of alloying aluminium and why 7075 is ideal for frame tubing. Despite its low density, 7075 aluminium has an ultimate tensile strength of 572 MPa (83000 psi). Aerospace companies are concerned about fatigue failure in 7075 aluminium. Even with a force below its yield point, a material can fail. If the material is cyclically stressed, microfractures can weaken it and cause it to break. Fatigue strength measures a material's ability to withstand cyclical loading and is useful when a part made from this material is subject to repetitive loading cycles (such as in aircraft or motor vehicles). 7075 aluminium has a 159 MPa fatigue strength (23,000 psi). This number is based on 500,000,000 cycles of constant, periodic loading below the yield point. This shows how a strong alloy can be broken over time by smaller forces. (Cavallo, 2022) . The summary of 7075 aluminium shown in Table 2.3 and the microstructure of pure Al 7075 shown in Figure 2.1.

Table 2.3: Summary of physical and mechanical properties of 7075 aluminium alloy.

Properties	**Metric**	**English**
Density	2.81 g/cm^3	0.102 lb/in^3
Ultimate Tensile Strength	572 MPa	83000 psi
Tensile Yield Strength	503 MPa	73000 psi
Shear Strength	331 MPa	48000 psi
Fatigue Strength	159 MPa	23000 psi
Modulus of Elasticity	71.7 GPa	10400 ksi
Shear Modulus	26.9 GPa	3900 ksi

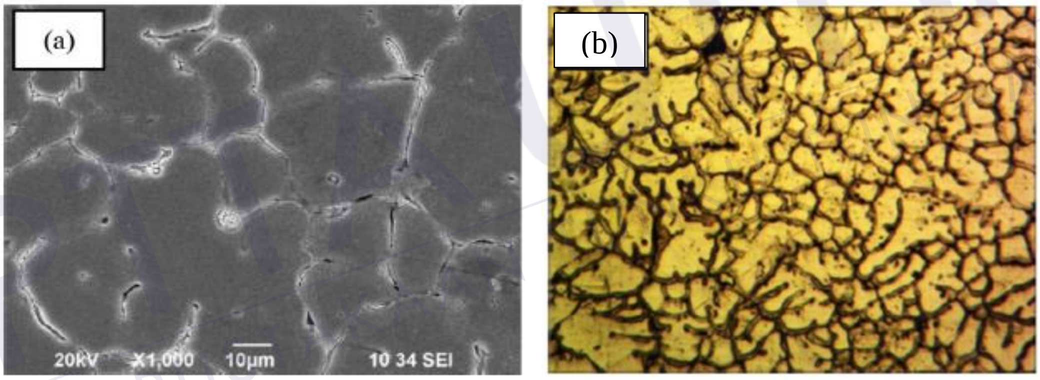

Figure 2.1 : Morphology image 7075 aluminium (a) SEM (b) Optical microscope (Robinson Smart et al., 2021).

2.2.3 Fabrication Process

Globally, metal machining processes generate vast quantities of metal scrap. In addition, the global demand for aluminium has increased, as the consumption of aluminium products has doubled and is projected to increase two to threefold by 2050 (Haraldsson & Johansson, 2018; Krishnan et al., 2019). As a result, there are two types of aluminium: primary and secondary. Primary aluminium is derived from the bauxite alumina, while secondary aluminium is derived from aluminium scrap (Mahinroosta

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VITAE

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