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Effect of Eggshell Waste as Reinforcement on Physical and Mechanical Properties of Recycled Aluminium Chip AA7075: A Review

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Abstract: The driving force for the application of aluminium metal matrix composites with waste product as reinforcement likes eggshells over ferrous and nonferrous alloys is due to the economic, performance and environmental benefits. Potential of using eggshells as reinforcement was investigated based on the literature review by studying the previous studies of physical and mechanical properties of the composite body. The previous studies were based on results and discussions of the properties which are hardness, compression, density and porosity properties of aluminium metal matrix composite (AMMC). The hardness has found to increase with increasing of reinforcement composition. The compression strength results shown related to hardness result. The density has found to effect the composite density cause influenced by the mass of reinforcement while porosity increased when the empty space between particles increased. Material selection for reinforcement is very important for influencing the properties of AMMC. A consolidated review is being carried out and conclusions are made.

Keywords: Metal Matrix Composite, Hardness, Compression, Density, Porosity.

1. Introduction

Most machines and high specification systems had been implemented in the process of productions and it caused for increasing in the total costs of the product. Because of that, they needed to maximize wastes which are produced during the production to be recycled to cut the costs. The development of the automotive sector has transformed into recycled material because their part of the product produces a ton of aluminium waste mainly due to the fact that the production and usage of vehicles is growing worldwide [1]. In addition, aluminium is a product from the mining of bauxite. Thus, the main factors of deforestation are industrial raw materials sources and also as disposal areas. To overcome those environmental issues, aluminium had been suggested and will be considered as valuable recycled materials to minimize the usage of primary aluminium.

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Besides, eggshell is also categorized as waste in industries same as aluminium chips but there is no maximize for the usage of eggshells such aluminium as recyclable materials. The disposal processes of eggshell are very costly for the industries especially food industries. The eggshells will cause environmental problems as the protein-rich membrane attracts rats [2]. Thus, this research purpose to study the sample works on recycled AA7075 chips and eggshells with a combination of compaction technique by referring and comparing from the previous studies. The potential of using eggshells as reinforcement in aluminium alloy is investigated by studying the characteristics of physical and mechanical properties of composites body. Both materials are being recycled and can be implemented at the industries to cut the cost and to save the energy used.

2. Materials and Methods

In this study, selection of journal articles that focused on the parameter of both compositions of composite and size of particles that effect the mechanical and physical properties of composite were systematically analysed. Data base search was performed on few well established data bases which are Scopus, ScienceDirect and ResearchGate. Keywords such as “aluminium chip”, “eggshell”, “composite” and “aluminium composite” were included in the search options and the scope was restricted to academic papers in English, including recent publications from year 2015 to 2020. For the first step, the terms “aluminium chip”, “eggshell”, “aluminium composite” and “cold compaction” were being searched. Then, the tittle, abstract and keywords were manually checked and selections were refined by removing all non-related papers. Next step, the related papers were searched through exploration and analysis of references with citations of previous selected papers. After that, in covering all experiments regarding compaction process, the searched papers were included with terms such a “effects”, “size of particles”, and “composition”. Lastly, a final clarification was made predicated on full texts and sorting of all papers were also predicated on full texts. All the progress of the working procedures was described as a flowchart and shown in Figure 1.

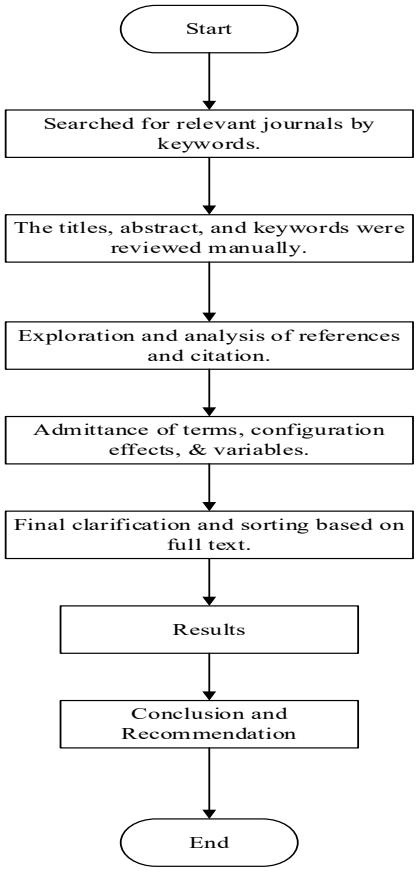

Figure 1: Flow chart of methodology process.

3. Results and Discussion

Experimental results of mechanical and physical properties for the AA7075 composite with eggshell particles as reinforcement was compiled and discussed according to the previous researches finding. The results and the effect of different compositions of composite and different size of eggshell particles were carried out and summarized. The experimental results based on objectives which were stated above by measuring on the hardness, compression, density and porosity. The previous results have taken based on the matrix which is AA7075 with eggshells and other reinforcements such as ceramic, rice husk ash, and chromium carbide, Cr_3C_2. All the comparisons between the previous results were discussed in this chapter.

3.1 X-ray Diffraction, XRD Patterns

By referring Figure 2, XRD patterns of eggshells powder at 25ºC shown the presence of calcium carbonate, $CaCO_3$ as the major phase which is about 78 %. Calcium carbonate appeared as calcite. The XRD results indicated that generally, eggshell contained calcium carbonate which is confirmed the calcium carbonate properties would appear obviously. The average crystallite size, D of calcium carbonate, $CaCO_3$ in the eggshells powder is about 40 nm.

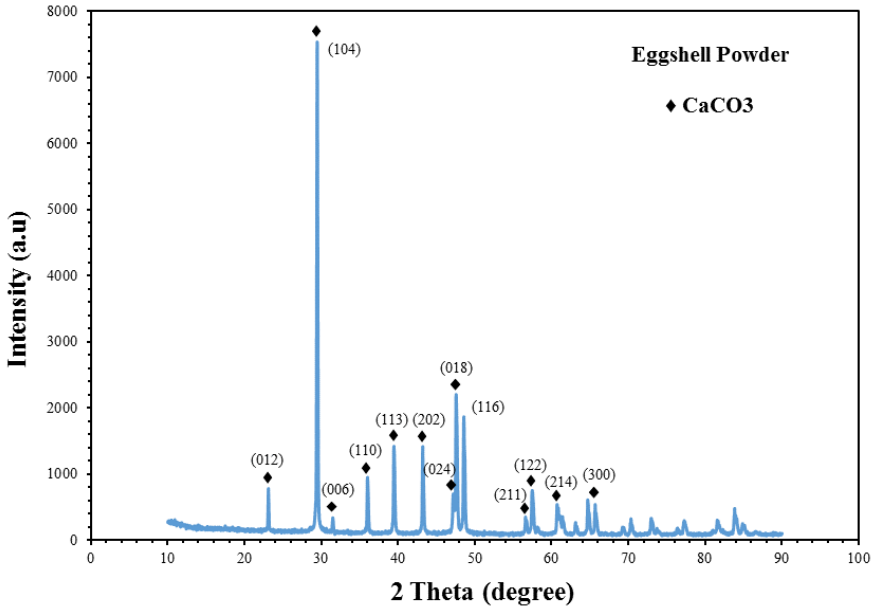

Figure 2: XRD pattern of eggshells powder [3]

3.2 Hardness test

Joharudin et al., described that the composite produced by the addition of amorphous silica from rice husk as reinforcements. Finally concluded that the hardness of the composites was improved by increasing the percentage of amorphous silica adding with AA7075 chips alloy. However, the hardness of matrix material was reduced with the increased composition of silica to more than 12.5 wt.%. This was caused by the poor wettability of the reinforcement and matrix material produced poor bonding between the particles [4]. Verma & Vettivel, reveals that AA7075 alloy composite reinforcement with boron carbide, B_4C and rice husk ash. The results show that the composites have enhanced the hardness by increasing the addition of reinforcements to 10 wt.%. According to this study, increased in the hardness of the composite would cause by the properties of reinforcement. Boron carbide, B_4C which is one of ceramic has hard particle properties cause hardness properties increased as the boron carbide acted as the properties of the dominant particles [5].

Agunsoye et al., described that the composite materials used eggshells as reinforcement materials that were added with A7075 alloy as matrix. The addition of 12 wt.% eggshells powder as reinforcements in the aluminium alloy which increased the hardness. Then the obtained final hardness is 77 Hv compared with pure AA7075 which is 66 Hv. Based on the study, the outstanding hardness of those composites was influenced by the selection of reinforcement which was eggshell particles [6]. Rao el al., described that the composite materials used chromium carbide, Cr_3C_2 powder as reinforcement materials that were added with A7075 alloy. The addition of 10 wt.% chromium carbide powder as reinforcements in the aluminium alloy which increased the hardness. The increase in hardness due to the good wettability which increased in strain energy caused by dispersing and dislocation of particles in the matrix. Besides, the hardness nature present in the reinforcement, chromium carbide, Cr_3C_2 particulates influenced the composites hardness properties. However, for the decreased of hardness was caused by increasing of porosity due to agglomeration and cluster formation between the reinforcement and matrix particles [7].

Madhukumar & Umashankar, described that the composite produced by the addition of glass particulate as reinforcements with AA6061 chip alloy as matrix. Finally concluded that the hardness of the composites was improved by increasing the percentage of glass particulate but with the smallest size which is 75 microns. However, the hardness of matrix material was reduced with the composition of glass particulate increased to more than 9 wt.%. This was caused by agglomeration and pores in the composite. However, the size of glass particulate particles with fineness size is the best significance in the increase of hardness to composite material since they are well distributed in it [8].Table 1 depicts the summaries of comparison for hardness test from previous researcher.

Table 1: Summary comparisons of hardness results from previous researches

Matrix material	Reinforcement	Fabrication process	Hardness test	Findings
AA7075 chips	Rice husk ash	1) Cold compaction 2) Sintering	Vickers hardness	Increased hardness
AA7075 rod	1)Boron carbide 2)Rice husk ash	Stir casting	Vickers hardness	Increased hardness
AA7075 can	Eggshell powder	Stir casting	Vickers hardness	Increased hardness
AA7075 ingots	chromium carbide (Cr3C2)	stir casting	Vickers hardness	Increased hardness
AA6061 ingots	Glass particulate	stir casting	Vickers hardness	Increased hardness

3.3 Compression Test

Kadir et al., described that the composite produced by the addition of aluminium powder as reinforcements with AA6061 recycle chip as matrix. Finally concluded that the compression of the composites was reduced by increasing the percentage of aluminium powder. It showed decreasing pattern linearly. Based on the result stated, the researcher concluded that by increasing the aluminium powder content, it will lead to weak bonding between particles while by decreasing the aluminium powder content, it will increase the bonding between particles. This is because the aluminium powder has high mobility which is can move and reposition themselves between the aluminium chip and caused to be more brittle. In addition, full aluminium chips increased the ductility properties which is increased the withstand stress [9]. Verma & Vettivel, reveals that AA7075 alloy composite reinforcement with boron carbide, B_4C and rice husk ash. The results showed that the composites were enhanced the compression by increasing the addition of reinforcements to 10 wt.%. Based on the researcher discussion, it stated that B_4C percentage effect the compression strength of the composite. In addition, it enhanced the strength but decrease the ductility by weak bonding between particles [5].

Zhang et al., described that the composite materials used boron carbide, B_4C powders as reinforcement materials that were added with aluminium powders. The addition of 15 wt.% B_4C as reinforcements in the aluminium which increases the compression strength. However, the obtained final compression strength with 25 wt.% of B_4C decreased linearly. Based on the study, the ceramic phase addition and defect of microstructure are influenced the compression strength and resistance for the composite properties. Besides, higher particles of B_4C in the composite would produce major heterogeneous grain boundary and lead to decrease in density and compression strength [10]. Ghasali et al., described that the composite materials which used boron carbide, B_4C powders as reinforcement materials that were added with aluminium powder as matrix. The addition of B_4C powders from 10 wt.% into 22 wt.% as reinforcements in the aluminium alloy resulted in the increasing of compression strength. By referring to the study, the aluminium matrix composite (AMC) has a smaller grain size which is leading to move grain boundaries. In addition, it can act as strong obstacles to the dislocation motion. Thus, it will increase the compressive strength of the composite [11].

Babu et al., described the study of a composite of AA6060 as a matrix with multiwall carbon nanotubes (MWCNTs) as reinforcement. The addition of MWCNTs which is 1 wt.% and 3 wt.% resulted in the decrease of compression strength. The compression strength decreased due to lower densification of the composites and worst bearing within the matrix of the composite. In addition, the lower integration between the aluminium and MWCNTs particles [12].Table 2 shows the summaries comparison for compression test result obtained from previous researcher.

Table 2: Summary comparisons of compression results from previous researches

Matrix material	Reinforcement	Fabrication process	Compaction load & time	Findings
AA6061 chips	Aluminium powder	1) Cold compaction, 2) Sintering	9 tons (20 min)	Decreased compression
AA7075 rod	1)Boron carbide 2)Rice husk ash	Stir casting	9 tons (20 min)	Increased compression
Al powder	Boron carbide	Vacuum hot press	9 tons (20 min)	Increased compression
Al powder	Boron carbide	1) Cold compaction 2) Sintering	9 tons (20 min)	Increased compression
AA6061powder	Multiwall carbon nanotubes (MWCNTs)	1) Cold compaction 2) Sintering	9 tons (20 min)	Decreased compression

3.4 Density and porosity test

Joharudin et al., described that the composite produced by the addition of amorphous silica from rice husk as reinforcements with AA7075 chip alloy as matrix. Finally concluded that the density of the composites was increased by adding the percentage of amorphous silica until 3 wt.%. However, the density decreased slowly after the addition of amorphous silica into 6 wt.%. Meanwhile, the porosity showed independently to the composition of amorphous silica since these properties showing consistent at increasing in the mass fraction of amorphous silica. The density of composite was influenced by the density of reinforcement which is amorphous silica from rice husk ash as known as the lightest material. The more the percentage of amorphous silica in the composite, the density decreased slowly. Otherwise, the porosity of composite showed constantly percentage because of the strong bonding between the amorphous silica and AA7075 chip caused by the sintering process and high wettability [4].

Rao et al., described that the composite materials used chromium carbide, Cr_3C_2 powder as reinforcement materials that were added with A7075 alloy. The addition of 7.5 wt.% chromium carbide powder as reinforcements in the aluminium alloy which increases the density and porosity. The density

of chromium carbide is more than the density of AA7075. Thus it would affect the whole density of composite produced. Besides, the increase of porosity cause of gas trapped during mixing, higher shrinkage rate while solidification and development of bubbles in the slurry between the Cr_3C_2 and AA7075 particles [7].

Hassan & Aigbodion, described that the composite materials used eggshells powder with carbonized and uncarbonized as reinforcement materials that were added with Al-Cu-Mg. The addition of 12 wt.% eggshells powder as reinforcements in the aluminium alloy which decrease the density for both carbonized and uncarbonized samples. The carbonized eggshell is less dense than uncarbonized eggshell. Thus, the composite with lightweight could be produced with eggshell as the reinforcement [13].

Kadir et al., described that the composite produced by the addition of aluminium powder as reinforcements with AA6061 recycle chip as matrix. With the addition of 10 wt.% to 50 wt.% of aluminium powder, the density dropped significantly. The density increases back to 70 wt.% content of Al powder until it hits maximum aluminium powder due to more possible bonding between particles. However, the percentage of porosity demonstrated a contradictory effect of density due to the fraction or percentage of pores within the volume of a porous solid. Thus, the highest porosity occurs when the amount of aluminium chip was at 50 wt.%. The increasing of aluminium powder after 50 wt.% will reduce the percentage of porosity and the same effect also happens when increasing the quantity of Al chip. In addition, density and porosity transformations can be evaluated as increasing sintered density resulted in a lower fraction of the pores. Meanwhile, based on the result shown the porosity properties have an opposite effect of density due to the percentage of pores related to the volume of porous solid [9].

Mohanavel el al., described that the composite which used silicon carbide, SiC powders as reinforcement materials that were added with AA6351. The addition from 4 wt.% until 20 wt.% of silicon carbide powder as reinforcements in the aluminium alloy which increases the density. Then the obtained final density is 2.79 g/cm^3 compared with pure AA6351 which is 2.69 g/cm^3. Based on the result also, the high density of SiC particles than the density of AA6351 were influenced the density of the composites [14]. Table 3 shows the summaries comparison for density and porosity result from previous researcher result.

Table 3: Summary comparisons of density and porosity results from previous researches

Matrix material	Reinforcement	Fabrication process	Findings
AA7075 chips	Rice husk ash	1) Cold compaction 2) Sintering	1) Decreased density 2) Constant porosity
AA7075 ingots	Chromium carbide (Cr3C2)	Stir casting	1) Increased density 2) Increased porosity
AA7075 can	Eggshell powder	Stir casting	Decreased density
AA6061 chips	Aluminium powder	1) Cold compaction 2) Sintering	1) Decreased density 2) Increased porosity
AA6351 plain	Silicon carbide, SiC powders	1) Stir casting	Decreased density

4. Conclusion

From the review of mechanical and physical properties development in aluminium matrix composite (AMC) with various compositions and particles size of reinforcement, the AMC reinforced by several types of material such as eggshell, rice husk and glass particulate which each of the materials have different properties. The material selection for reinforcement is the most important things which can influence the properties of composite besides the composition and size of particles. Based on the

discussion, the ceramic material such as boron carbide produced higher mechanical and physical properties of composite because the ceramic is higher density and hardness material. Meanwhile, eggshell produced lower mechanical and physical properties of composite because the eggshell is lower density but high hardness material. However, the eggshell can be used for another application especially in the lighter material composite product.

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References

[1] L. Kuchariková, E. Tillová, and O. Bokůvka, "Recycling and properties of recycled aluminium alloys used in the transportation industry," *Transp. Probl.*, vol. 11, no. 2, 2016, doi: 10.20858/tp.2016.11.2.11.

[2] U. Osonwa, "Egg Shell Powder as a Potential Direct Compression Excipient in Tablet Formulation," no. August, 2017.

[3] R. Choudhary, S. Koppala, and S. Swamiappan, "Bioactivity studies of calcium magnesium silicate prepared from eggshell waste by sol-gel combustion synthesis," *J. Asian Ceram. Soc.*, vol. 3, no. 2, pp. 173–177, 2015, doi: 10.1016/j.jascer.2015.01.002.

[4] N. F. Mohd Joharudin *et al.*, "Effect of amorphous silica by rice husk ash on physical properties and microstructures of recycled aluminium chip AA7075," *Materwiss. Werksttech.*, vol. 50, no. 3, pp. 283–288, 2019, doi: 10.1002/mawe.201800229.

[5] N. Verma and S. C. Vettivel, "Characterization and experimental analysis of boron carbide and rice husk ash reinforced AA7075 aluminium alloy hybrid composite," *J. Alloys Compd.*, vol. 741, no. April, pp. 981–998, 2018, doi: 10.1016/j.jallcom.2018.01.185.

[6] J. O. Agunsoye *et al.*, "Recycled aluminium cans/eggshell composites: Evaluation of mechanical and wear resistance properties," *Tribol. Ind.*, vol. 37, no. 1, pp. 107–116, 2015.

[7] V. R. Rao, J. R. Chowdary, and S. P. K. Gudapati, "Fabrication and investigation on mechanical properties of (AA7075/Cr3C2) metal matrix composites," *Mater. Today Proc.*, vol. 23, no. xxxx, pp. 513–517, 2020, doi: 10.1016/j.matpr.2019.05.397.

[8] Madhukumar and Umashankar, "Characterization and Effect of Particle Size on the Mechanical Properties of Glass Particulate Reinforced Aluminium Alloy6061 Metal Matrix Composites," *Mater. Today Proc.*, vol. 5, no. 5, pp. 12872–12876, 2018, doi: 10.1016/j.matpr.2018.02.272.

[9] M. I. A. Kadir, M. S. Mustapa, N. A. Latif, and A. S. Mahdi, "Microstructural Analysis and Mechanical Properties of Direct Recycling Aluminium Chips AA6061/Al Powder Fabricated by Uniaxial Cold Compaction Technique," *Procedia Eng.*, vol. 184, pp. 687–694, 2017, doi: 10.1016/j.proeng.2017.04.141.

[10] L. Zhang *et al.*, "Microtopography and mechanical properties of vacuum hot pressing Al/B4C composites," *Ceram. Int.*, vol. 44, no. 3, pp. 3048–3055, 2018, doi: 10.1016/j.ceramint.2017.11.065.

[11] E. Ghasali, M. Alizadeh, T. Ebadzadeh, A. H. Pakseresht, and A. Rahbari, "Investigation on microstructural and mechanical properties of B4C-aluminum matrix composites prepared by microwave sintering," *J. Mater. Res. Technol.*, vol. 4, no. 4, pp. 411–415, 2015, doi: 10.1016/j.jmrt.2015.02.005.

[12] J. S. S. Babu, C. H. Lee, and C. G. Kang, "Study of the mechanical and workability properties of extruded aluminium (Al6061) based composites reinforced with MWCNTs," *J. Mater. Res. Technol.*, vol. 9, no. 3, pp. 5278–5292, 2020, doi: 10.1016/j.jmrt.2020.03.054.

[13] S. B. Hassan and V. S. Aigbodion, "Effects of eggshell on the microstructures and properties of Al–Cu–Mg/eggshell particulate composites," *J. King Saud Univ. - Eng. Sci.*, vol. 27, no. 1, pp. 49–56, 2015, doi: 10.1016/j.jksues.2013.03.001.

[14] V. Mohanavel, K. Rajan, S. S. Kumar, S. Udishkumar, and C. Jayasekar, "Effect of silicon carbide reinforcement on mechanical and physical properties of aluminum matrix composites," *Mater. Today Proc.*, vol. 5, no. 1, pp. 2938–2944, 2018, doi: 10.1016/j.matpr.2018.01.089.