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Utilization Of Beverage Cans Waste As A Metal Matrix Composite

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Abstract. Waste of beverage cans has not been utilized properly so far and it tends to cause environmental pollution. Thus, the efforts are required to utilize the waste material from these cans into useful or advance product. Currently, there are many technological advancement applications requiring such components that have mild but good in mechanical properties. This work tries to utilize the soft drink beverage cans waste as a main raw material. By utilizing the heat at temperatures above recrystallization accompanied by nitrogen infiltration to inhibit porosity, followed by the addition of magnesium as a wetting agent. The combination of those materials will facilitate in improving the produced mechanical properties. The utilization of beverage cans as a metal matrix composites is expected to be able to maintain environmental balance, because it cannot be naturally degraded. In this work, the beverage cans serve as a matrix, the alumina (Al_2O_3) of 10-20 vol.% used as reinforcement, and magnesium (Mg) of 14-16 % of weight percent as a wetting agent. The result shows that the composition combination of 20 vol.% of weight percent Al_2O_3 and 14 vol.% of weight percent Mg produces the highest mechanical properties and evenly distributed constituent. Thus, the waste of beverage cans based on aluminum AA3104 is highly recommended to be used as a matrix combined with reinforcement of Al_2O_3 and wetting agent of Mg. It is proposed that by using beverage cans waste as metal matrix composite (MMC), the land pollution can be reduced and environmental balance can be enhanced properly.

Keywords: Beverage cans; Aluminum; Magnesium; Alumina, Metal Matrix Composites

1. Introduction

Waste of beverage cans, has not been utilized properly, so it tends to cause environmental pollution. The number of consumption of soft drink cans in Indonesia reaches about 200 million annually. So, concerted efforts are needed to utilize the waste material of cans^{1,2}. Cans consist of three main components namely the body, the bottom cover and the top cover. The elements of Al, Fe, Mn, and Si are commonly combined in aluminum alloys which are used as raw material for the manufacture of pressurized beverage cans (carbonation), with the drawn wall ironing (DWI) process. These alloys produce solid $Al_2(Fe, Mn)_3Si$ known as the AA3104 series alloys³. The development of material technology is now beginning to switch into components that have mild properties, but good in mechanical properties, and resistant to corrosion^{4,5}. Metal matrix composites (MMC) are materials made with a combination of two or more different materials that are combined in a microscopical scale. As such, materials with better and more useful properties are formed, if there is a bond between the two



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of materials⁶⁻⁷. MMC is a material that is being developed and perfected several of its properties. As an alternative metal substitute which is potential in meeting a series of properties that can be adapted for certain applications⁸⁻⁹.

The experiment refers to the utilization of soft drink of beverage cans as a matrix that is applied for MMC. By utilizing heat at temperatures above its recrystallization accompanied by nitrogen infiltration, to inhibit porosity, accompanied by the addition of magnesium as a wetting agent, the combination of these materials can improve the produced mechanical properties¹⁰. Each element has a role in the composition of composites. Cans which are part of the AA3104 series aluminum have a role as a matrix (a dominant composition), while Al_2O_3 acts as a reinforcement. Aluminum cans, including metals, and Al_2O_3 belong to the ceramics group, are difficult to put together. So, the role of magnesium here is required as a wetting agent. As such, the matrix of aluminum cans with reinforcement from alumina ceramic can be forged into a properly strong bond. The utilization of beverage cans with alumina reinforcement will be applied into MMC applications. The main purpose of this work is to utilize the beverage cans as a low-cost and main ingredient of MMC. In future, it is expected to contribute into maintaining the environmental balance and scalable for mass production.

2. Method

The main materials used in the experiment were aluminium beverage cans based on AA3104, alumina (Al_2O_3) fibers as reinforcement, and magnesium as wetting agent of the matrix - reinforcement. The perfection of the bond produced was influenced by the temperature of the process and also how the role of nitrogen could minimize the porosity in reaction between aluminum, magnesium and Al_2O_3 . The cans were cut into small pieces and then ground into powder with Then, powdered alumina and magnesium were prepared for mixing in a dense structure, as shown in Fig 1. A tube furnace was used for the heating process, nitrogen was also used to maintain the combustion process oxidation, and to help the infiltration process of the aluminum into the reinforcement. The materials were heated up in 700-800 °C for 5 h to achieve full-infiltration. The sample was then air-cooled down until reaching room temperature.

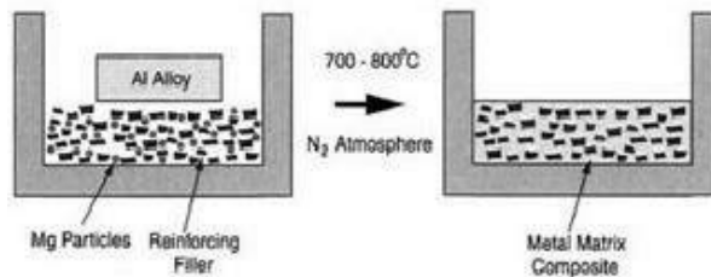


Figure 1. Scheme of process infiltration of composite materials based on canned waste

The composite sample was tested for density and porosity. Scanning Electron Microscope (SEM) was used to determine the morphology of grains and deposition distribution resulted from aluminum cans. The sample was properly prepared; the magnification was done in 2000-5000 x. This investigation was carried out based on three essential steps; preparing the composite sample from the cans combined with Al_2O_3 and magnesium

3. Results and Discussion

3.1 Physical and Mechanical Properties of the MMC

The porosity and density test of the MMC based on aluminium beverage cans are presented in Table 1. Testing the density obtained graphs of the relationship between the effects of adding the percentage of elemental magnesium in the matrix at each volume fraction. The MMC with composition of 70 vol.% Al: 14-16 vol.% Al_2O_3 shows a density value of 2.25 g/cm³; by adding 15 vol.% Mg, the density value decreases to 1.80 15 g/cm³; and by adding 16 vol.% Mg, the density has increased to 2.267 g/cm³. This happens due to the main properties of the AA3104 aluminum that were used as a matrix has a poor flowability. This is due to the high thermal conductivity of aluminum and its alloys, making it difficult to pour. In addition, it can be explained that the main alloy composition of AA3104 is manganese whose flowability is low and causes the matrix to decrease. Meanwhile, the increase in the density is addressed by the increase of the diffusion of Al that is able to soak the Al_2O_3 properly.

Furthermore, the constituent of volume fraction of Al_2O_3 as reinforced is quite high (14-16 vol.%). In this condition, the magnesium is unable to wet the Al_2O_3 particles and recover the pore of the MMC. Therefore, the sample density decreases. The decrease in density is caused by part of the aluminum which melts, but not wetted by magnesium. This results in some pores that are not being closed due to the lack of wettability of magnesium, implying that the density of the composite increases. The number of additions of 14-16 vol.% of Mg does not have a wide range on changing of density values. Generally, the value of density tends to decrease if the level of reinforcement is increased and the value of density will increase if the level of reinforcement decreases¹¹. With the addition of magnesium as much as 16 vol.%, the density increases. This is due to the enhancement of the bonding between the constituent of matrix-reinforce as a consequence of increasing the wettability of constituent. Due to greater bondage, the density of the material increases and the density value will also be higher¹².

Table 1 Mechanical and physical properties of beverage cans based MMC

Composition of Al_2O_3 : Mg	Experimental Density (gr/cm^3)	Theoretical Density (gr/cm^3)	Porosity (%)	Hardness (BHN)
20: 14	2.25	2.71	17	208
20 : 15	1.80	2.61	33	168
20 : 16	2.26	2.69	15	108
10 : 14	2.16	2.55	16	103
10 : 15	1.99	2.57	22	69
10 : 16	2.15	2.57	16	49

From the porosity results (Table 1), the MMC porosity value tends to decrease. When magnesium is added as much as 16%, causes nitrogen gas to be trapped. Another reason is the shrinkage that occurs during sample compaction which is the main rationale of porosity formation. This results in a reduction in volume and followed by its hardening. Porosity is formed due to trapped gas, resulting from a decrease in the gas solubility in solids⁴. The porosity value tends to decrease due to the increased wettability of magnesium to wet the aluminum and Al_2O_3 , thus filling the pores in the MMC sample. The dominant composition of beverage can waste also affects the reduced volume fraction of Al_2O_3 composition as a reinforcement. This also affects the increasing magnesium capacity in wetting the matrix and reinforcement, results in decreasing the porosity number. On the contrary, the Al_2O_3 as reinforcement in MMC makes it difficult for the matrix to be infiltrated. This phenomenon causes the increase of MMC porosity. The highest porosity occurs when adding 15 vol.% Mg into the matrix, namely 33 % and 22 %. The decrease in the porosity occurs when adding 16 vol.% Mg into the matrix, i.e., 15 % Generally, the decrease in porosity occurs due to the increasing percentage of wetting agents that cause the wetting ability of aluminum and alumina is enhanced. Thus, aluminum infiltration fills more the Al_2O_3 pores resulting in an increase in density which means the porosity value decreases⁹⁻¹¹. The added magnesium can influence the hardness value with the same Al_2O_3 volume fraction addition. The addition of magnesium content to the MMC will be inversely proportional to the value of hardness. This result is contrary with the research⁹ which explains that the severity of the product reaction will increase with increasing percentage of magnesium. The results of composite-based beverage cans waste shows in contrary to previous hypotheses about the value of hardness obtained will decrease with increasing percentage of the magnesium added into the matrix. One of the reasons causing this is the occurrence of segregation due to the large amount of magnesium added to the Al- Al_2O_3 matrix. This segregation is caused by the significant melting point differences between magnesium and the aluminum matrix. So, during the freezing process, the aluminum freezes first then followed by the magnesium freezing. Magnesium freezing process is slower than aluminum and this causes magnesium to gather in the middle (localized agglomerate) resulting in decreasing its mechanical properties. Generally, the aluminum matrix composites with 10 vol.% Al_2O_3 have lower hardness values compared to 20 vol.% Al_2O_3 .

Hardness testing using the brinell (BHN) method with identifier media in the form of a 2.5 mm diameter steel ball with 612.9. Form Table 1, it shows that the composite matrix of 20 vol.% Al_2O_3 with magnesium of 14 vol.% has the highest hardness number of 208 BHN. While, the addition of 15 vol.% magnesium is lowering the obtained hardness value than the

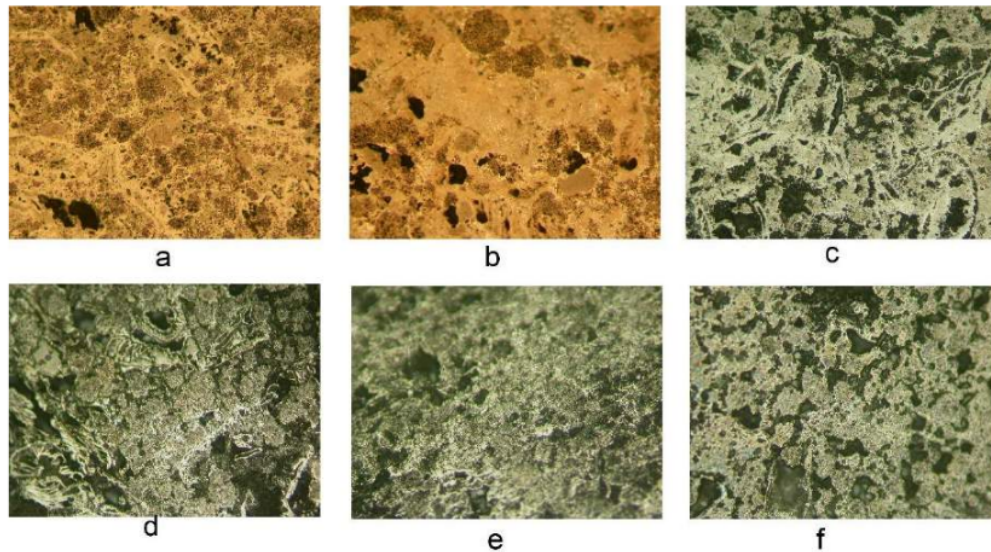
addition of 14 vol.% magnesium, i.e., 168 BHN. The lowest hardness value of MMC with 20 vol.% Al₂O₃ was obtained when the addition of 16 vol.% magnesium that is 108 BHN. The higher value of hardness obtained in the alloy composition is due to the contribution and distribution of the reinforcement where the number of reinforcement addition in this work is relatively large (up to 10-20 vol%). So, this will contribute to its better obtained hardness value. With the addition of 14 vol.% magnesium, the obtained hardness value was 103 BHN. However with the addition of 15 and 16 vol% magnesium, the composite formed decreased lower than the hardness value of 14 vol.% magnesium, namely 69.1 and 49 BHN. Another reason that causes a significant difference in the obtained hardness value is the high number percentage of added magnesium. This can be explained as follows; the addition of magnesium into the matrix composite is as a wetting agent where has the role to wet the Al₂O₃ as a reinforcement. Thus, it is expected to be infiltrated completely within the aluminum matrix. Meanwhile, the Al₂O₃ reinforcement has higher melting temperature. So, when the temperature reaches at 850 °C, the Al₂O₃ does not burn or melt. Therefore, a few percentages of magnesium are added to protect or soak Al₂O₃ not to burn. However, too much magnesium addition is reduced ineffective of formed MMC. The size effect needs to be accounted. The increase in hardness depends on the size of the grain produced. The finer the grain size the higher the yield stress produced. As presented in equation (1), the yield stress is linear with hardness, the higher the yield strength, the higher the hardness, as shown in Table 1. The description of the equation (1) is explained in accordance with the theoretical rules of hal petch¹³.

$$\sigma_y = \sigma_0 + k_y \cdot d^{-1/2} \dots \dots \dots (1)$$

Where *d* is grain size, σ_y is yield strength, σ_0 is friction stress and k_y is a constant of strength. From equation (1), it shows that decreasing the grain size increases the strength of materials. This has attracted interest among scientists and industry to the pursue of MMCs on the processes. To refine grain size of commercial alloys, thermo-mechanical treatment is necessary. The applied temperature must be sufficient to provide formability, but must be kept below the crystallization temperature to inhibit grain growth due to the diffusion. To meet the high properties of MMC, it is highly recommended to continue to increase the number of stress cycles used.

3.2 Microstructure Morphological Observation of the MMC

Microstructure observation is to analyse the phase structure that is formed from the composites and to determine the distribution within the matrix and reinforcement of Al₂O₃ and magnesium as a wetting agent during the process. Observation of this microstructure was carried out by using optical microscope (OM). Figure 2(a) shows the composite material of 20 vol.% Al₂O₃ and 14 vol.% magnesium. It shows that Al₂O₃ has been distributed evenly on the sample surface. The aluminum matrix also seems to have melted completely and binds well to the reinforcement and wetting. This is probably due to the number of compositions of magnesium which is optimal in the matrix. However, there are a number of pores in certain parts that are caused by uneven wetting by the magnesium. Another reason, the presence of pores in the composite can also be due to the presence of other alloying elements that evaporate which can be found in the matrix materials (aluminum beverage cans). Figure 2(b) shows the composites with 20 vol.% Al₂O₃ and 15 vol.% magnesium that appear not so different to the 14 vol.% magnesium addition as in Figure 2(a). The Al₂O₃ is evenly distributed throughout the surface of the composite and the aluminum has melted completely. But in these composites, it is seen that the spread of magnesium as a coupling agent is less evenly distributed. Thus, causing the presence of pores in the composites with the 15 vol.% magnesium. Figure 2(c) shows the morphology of composite material with a composition of 20 vol.% Al₂O₃ and 16 vol.% magnesium. It looks different from the composite material of 14 vol.% magnesium. There is an uneven distribution of Al₂O₃ that has not infiltrated completely within the aluminum matrix. This is because the percentage of the addition of magnesium as a coupling agent into the matrix is quite a lot (16 vol.%). This is causing such a high wetting in Al₂O₃ and then it only infiltrates into certain areas of the matrix. Furthermore, the addition of 16 vol.% magnesium also causes a number of formed pores. Figure 2(d) shows the composite material of 10 vol.% Al₂O₃ accompanied by the addition of 14 vol.% magnesium. It shows the microstructure of the composite which has been quite well distributed.



Figures 2 Optical microscope observation of MMC morphology with 100x magnification: (a). 20 vol.% Al₂O₃ : 14 vol.% Mg (b). 20 vol.% Al₂O₃ : 15 vol.% Mg (c). 20 vol.% Al₂O₃ : 16 vol.% Mg (d). 10 vol.% Al₂O₃ : 14 vol.% Mg (e). 20 vol.% Al₂O₃ : 15 vol.% Mg (f). 10 vol.% Al₂O₃ : 16 vol.% Mg.

The spread of Al₂O₃ as a reinforcement is not evenly distributed on each surface so that it cannot be infiltrated completely with aluminum as a matrix for composites. In addition there are also a small number of pores that are spread on various surface areas of the composite in quite a large amount. However, it appears that the role of magnesium as a coupling agent is quite good with the appearance of Al₂O₃ as reinforced can be well wetted by magnesium. This shows that the addition of magnesium percentage which is quite optimal in the composite matrix. Figure 2(e) is a composite material with 10 vol.% Al₂O₃ and 15 vol.% magnesium seems not so different with the microstructure of 10 vol.% Al₂O₃ and 14 vol.% magnesium (Figure 2(a)). It is seen that the spread of Al₂O₃ as a reinforcement is also less evenly distributed on the matrix because the percentage fraction of Al₂O₃ volume decreases with increasing percentage of magnesium added. In addition, there are a large number of pores that are spread on each surface of the composite in quite a large amount.

Table 2 Results of EDS analysis of MMC based beverage can waste composite of 20 vol.% Al₂O₃ and 16 vol.% Mg:

Spectrum	Al	Mg	N	C	Al ₂ O ₃
Spec Oxide (%)	56.4	5.2	33	2.8	2.6
Spec Pure (%)	41.68	3.8	24.6	2	28

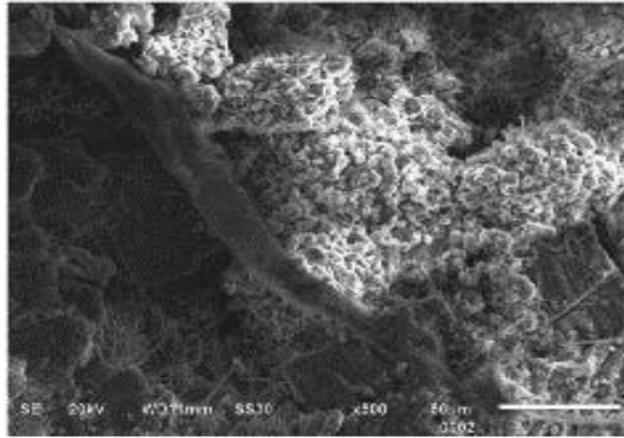


Figure 3. SEM spot morphological analysis result of AA3104 aluminum matrix composite with 20 vol.% Al_2O_3 and 16 vol.% Mg addition at magnification of 500x.

Figure 2(f) shows the composite material with a volume fraction of 10 vol.% Al_2O_3 and the addition of 16 vol.% magnesium. Its morphology is also similar as the composite of 10 vol.% with the addition of 14 vol.% and 15 vol.% magnesium discussed earlier (Figure 2(d) and 2(e)). The microstructure of this composite material shows a large number of pores which is spread over several surfaces of the composite formed. The Al_2O_3 is also not distributed or not evenly infiltrated within aluminum matrix. This is due to the small percentage of the volume fraction of Al_2O_3 in the composite. The magnesium is also added as much as 16 vol.% to the composite with a relatively small percentage of Al_2O_3 at only 10 vol.%. However, the role of magnesium as a coupling agent can function well by wetting the Al_2O_3 . In addition, to find out the phase structure formed, this microstructure observation was carried out to determine the percentage of pores and microstructure in Al- Al_2O_3 -Mg composite samples. From the OM observation, it is seen that a number of pore areas is increasingly widespread and varied. The microstructure of aluminum matrix based cans waste composite with 20 vol.% magnesium shows a good morphological structure with less so well. So the process of reinforcement infiltration with the matrix can take place perfectly. This is due to the small volume fraction of Al_2O_3 as reinforcement with the addition of magnesium which is quite a lot, so that Al_2O_3 is not spread evenly and only infiltrated in certain parts of the aluminum matrix. The even distribution of Al_2O_3 on each surface and aluminum melting as matrix with 10 vol.% magnesium. The process of heating is not optimal where the magnesium which is supposed to wet Al_2O_3 and to bind the aluminum, it occurs expansion on it. Therefore, the aluminum is not bounded by Al_2O_3 properly, thus causing such pores. Another reason is the uneven distribution of nitrogen gas flowing during the melting process.

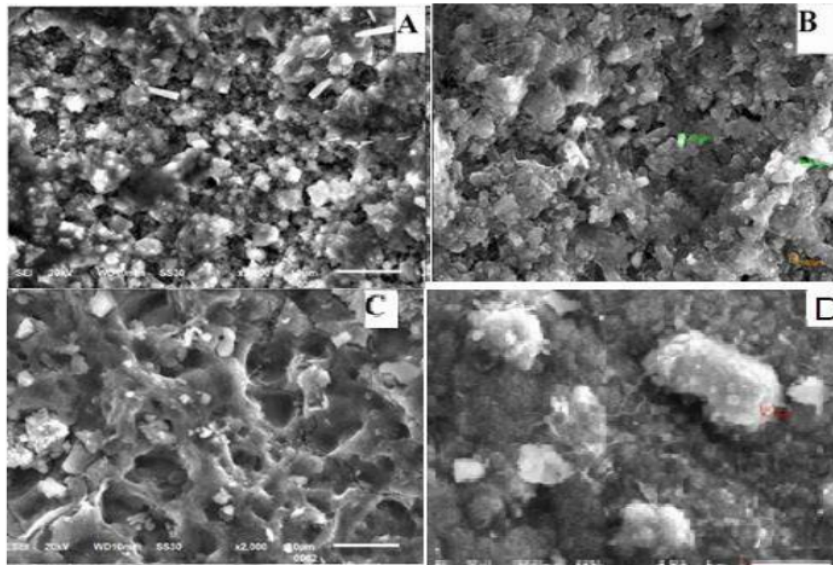


Figure 4. SEM results of composite with (a) 20 vol.% Al₂O₃: 14 vol.% Mg with 2000x magnification, (b) 20 vol.% Al₂O₃: 15 vol.% Mg with 5000x magnification, (c) 10 vol.% Al₂O₃: 15 vol.% Mg with 2000x magnification, (d) 10 vol.% Al₂O₃: 16 vol.% Mg with 5000x magnification

The SEM spot analysis of MMC based beverage can waste composite of 20 vol.% Al₂O₃ and 16 vol.% Mg is presented in Figure 3. One point that is considered to represent the entire sample can be seen in the distribution of microstructure and composition of chemical elements. This is carried out to find some levels of elements contained in the phase formed during the process. The EDS results is collected as in Table 2. In the oxide spectrum, the amount of aluminum, magnesium and nitrogen is greater than in the pure spectrum. This results in the emergence of dominant porosity. Microstructure observation by using SEM is carried out to determine the grain morphology, the grain seems uniform distribution for the aluminum matrix, however the Al₂O₃ and magnesium reinforcement is still not uniform, as shown in Figure 4. From the SEM results, it is also presented that grain size of 15 vol.% magnesium is finer than grain size of 16 vol.% magnesium, as shown in Figure 4(c) and 4(d). The wetting process with a composition of 14 vol.% magnesium results in better infiltration process of the aluminum matrix into alumina that is also relevant with its better produced mechanical properties. The percentage of magnesium between 14-16% produces fine grains, but also depends on the flow of nitrogen infiltration gas and heat adsorption.

4. Conclusions

The addition of magnesium in aluminum canned waste based matrix contributes to better infiltration process of the reinforcement within the matrix. However, too much magnesium addition will tend to reduce the obtained hardness value.

The difference in colour shows the dominant phases formed. The colour that has the brightest appearance is the aluminum element which has a large percentage as a matrix. The light gray colour is an

element of Al_2O_3 as a reinforcing medium. The dark gray appearance is magnesium as a wetting agent and the dark black appearance is a pore formed on the composite material.

Aluminium beverage cans waste based on AA3104 is considered to be used as a good matrix in the manufacturing of composites by using a reinforcement of Al_2O_3 and wetting agent magnesium. By using the aluminum Aluminium beverage cans waste as MMC, it will contribute to reduction of soil pollution and the environmental balance can be controlled properly.

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PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9
