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Solid Waste Management: The use of Broken Waste Bottles as Reinforcement Agent for Aluminum Matrix Composite

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ABSTRACT

Broken bottles and glasses have constituted a serious waste management problem. These broken bottles are dangerous and can inflict serious body injury if stepped upon accidentally. This research work has investigated the use of these broken bottles as reinforcement agent for the production of Particles Reinforced Aluminum Matrix Composite (PAMC). The developed composite using waste bottles and glasses in aluminum matrix had improved mechanical properties of the composite. The investigated mechanical properties were hardness and tensile strength. Tensile strength values for the as-cast composite which was produced using stir cast method were all greater than that of the monolithic aluminum which has a tensile strength value of $90N/mm^2$. The aged hardened composite also showed improvement over the as-cast composite indicating that the composite responded to age hardening. All values of hardness and tensile strength were higher in the case of the age hardened composite. Observations of microstructure revealed precipitate formation of the second phase in the case of the age hardened composite. The work has revealed that waste bottles can be used in improving the mechanical properties of monolithic aluminum.

Keywords: *solid waste, management, waste bottles, aluminum, and composite.*

1. INTRODUCTION

Glasses fall within the subgroup of ceramics called amorphous ceramics. They include those as ‘obsidian’ which occur naturally, and man-made glasses used for the manufacture of bottles, windows, and lenses [1]. Glasses are brittle and it is a common thing to find broken bottles, window glasses and other glass products littering the streets and residential areas in Nigeria and other developing countries. These broken bottles do constitute serious environmental hazards and could equally cause serious injuries should one step on them with bare foot. Recycling of the broken glasses for production of new products could reduce the challenge posed to the environment by this form of solid waste. Unfortunately this form of solid waste is not biodegradable neither is it water soluble. The option left is therefore recycling to clear it from the environment.

Pure aluminum has light weight, high conductivity and is used for power transmission cable. Aluminum however, lack strength and that is why pure aluminum is not used in load bearing structures. The strength of pure aluminum can however be increased by reinforcing it with hard particulates or fibres. For instance the elastic modulus of pure aluminum can be enhanced from 70GPa to 240GPa by reinforcing with 60 vol % of continuous aluminum fibre. Similarly, it is possible to process Al-9%Si-20% vol SiC composite having wear resistance equivalent or better than that of grey cast iron [2]. It has been pointed out that aluminum metal composite material systems offer superior combination of properties (profile of properties) in such a manner that today no existing monolithic materials can rival [2]. Aluminum composites reinforced by particles have received considerable attention because of their superior mechanical properties over monolithic aluminum-matrix [3]

A composite is a mixture of two or more distinct constituents or phases. However, this definition is not sufficient and three other criteria have to be satisfied before a material can be said to be a composite. First, both constituents have to be present in reasonable proportions, say greater than 5%. Secondly, it is only when the constituent phases have different properties, and hence the composite properties are noticeably different from the properties of the constituents that we have come to recognize these materials as composites [4]. However, if ceramic particles are somehow mixed with a metal to produce a material consisting of the metal containing a dispersion of the ceramic particles, then this is a true composite material [4].

In the continuing quest for improved performance, which may be specified by various criteria including less weight, more strength and lower cost, currently –used materials frequently reach the limit of their usefulness. Thus materials scientists, engineers and scientists are always striving to produce either improved traditional materials or completely new materials. Composites are an example of the latter category.

The objective of this research work is to see how this form of solid waste can be converted into useful form and possibly utilized as a reinforcing agent in aluminum matrix composite. The success of the research work will create an area for the consumption of broken bottles and glass products thereby reducing the load of the solid waste on the environment.

2. MATERIALS AND METHODS

2.1 Materials

The materials used for the production of the aluminum – glass composite material included, pure aluminum from electrical cable wire, etchant and broken bottles. The composition of the broken bottles is shown in Table 1.

Table1: Composition of Broken Bottles

S/no.	Composition	Percent
1.	SiO_2	72
2.	Na_2O	15
3.	CaO	9
4.	MgO	4

2.2 Equipment

Equipment used in this study included, melting furnace, gravity metal casting mould, electronic weighing balance, mechanical stirrer, oven, cutting saw, Rockwell hardness tester, Denison universal strength testing machine, grinding and polishing machine, and metallurgical microscope.

2.3 Methods

The test samples which were mainly aluminum-glass metal-matrix composite were produced using stir cast method. Test samples of diameter 20mm x height 350mm were cast in gravity metal casting moulds. The cast test samples were cut to size, prepared for hardness and tensile strength test. The best composition of the composite was given age hardening treatment. Microstructures of the as-cast, as well as that of the age hardened composite were examined.

2.4 Charge Preparation

The aluminum cable which was cut to pieces was preheated in the furnace to a temperature of $300^{O}C$ to dry-off any oily dirt coatings that may be present on the surface of the cable wire. The broken bottles were crushed and pulverized. The pulverized powder was sieved with 90чm sieve aperture. The -90чm (passing) particles size was used for the research work.

2.5 Charge Calculation

The reinforcement was calculated ranging from 0.5- 2.5% of the total charge at 0.5% interval and were identified as samples 1,2,3,4, and 5 respectively. Aluminum made the balance of the charge. The total charge per heat was 1200g.

Calculation for sample 1
Mass of reinforcement material = 0.5/100 x 1200g =6g.
Mass of aluminum = 99.5/100 x 1200= 1194
Total charge= 6 + 1194 =1200g
This process was repeated for samples 2, 3, 4, and 5 to obtain the values in the table below:

Table 2: Charge Composition

Materials	**samples**									
	1		2		3		4		5	
	%	g	%	g	%	g	%	g	%	g
Broken glass	0.5	6	1.0	12	1.5	18	2.0	24	2.5	30
Aluminum	99.5	1194	99	1188	98.5	1182	98	1176	97.5	1170
Total	100%	1200g	100%	1200g	100%	1200g	100%	1200g	100%	1200g

Each of the components of the charge was weighed with electronic (digital) scale in accordance with the calculated values on the above table.

2.6 Melting

Crucible furnace was used for the melting of the compositions. The crucible pot was preheated to red-hot before charging the required quantity of aluminum into the pot. The charged aluminum was heated to the melting temperature of aluminum ($660^{O}C$) and further superheated to the temperature of $700^{O}C$. The powder glass (reinforcement) was preheated to a temperature of about $150^{o}C$ to set it free from physical moisture. The reinforcement agent was introduced into the molten aluminum in the furnace and the combined charge was allowed to heat-up altogether, to a temperature above $700^{o}C$, to allow for proper mixing of the components of the composite. The molten charge was stirred consistently at the rate of 315 rpm to ensure proper mixing before casting. The stirring continued until the molten metal became partially viscous. The viscosity of aluminum is known to increase with solid impurities (particulates) [7]. To avoid the molten metal been too viscous it was quickly poured after the mixing into the metal mould. The metal in the mould was allowed to cool before shakeout to bring-out the aluminum-glass composite.

2.7 Tensile Strength Test

The tensile strength property was determined using Tinus-Olsen test machine. The test pieces were machined to the standard shape and dimensions as specified by the American Society for Testing and Materials (ASTM) [8]. The tensile strength was determined for the as-cast samples and for the best composition which was solutionized at 500^{o}C, quenched in water at 65^{0}C and aged hardened at 190^{o}C.

2.8 Hardness Test

The hardness test values for the as-cast samples and the best composition which was solution treated at 500^{o}C, quenched in water at 65^{0}C and age-hardened at 190^{o}C was determined using Rockwell hardness testing machine. The indenter used was a 1.56mm steel ball, and a minor load of 10kg and major load of 100kg were applied. Rockwell B scale and hardness standard block were used as recommended by American Society for Testing and Materials (ASTM) [9].

2.9 Microstructural Examination

Metallographic specimens were cut from the as-cast and age-hardened samples of the aluminum-glass particulate composite. The cut samples were mounted in Bakelite, and ground progressively using grinding machine with grade of paper ranging from 80-600 grits sizes using water as the coolant. The samples were polished using one-micron size alumina polishing powder suspended in distilled water. The final polishing was carried-out using 0.5 micron alumina polishing powder suspended in distilled water. Following the polishing operation, etching of the polished samples was done using Keller's reagent. The structure obtained was photographically recorded using an optical microscope with built-in camera [10].

3. RESULTS AND DISCUSSION

3.1 Results

The results of the effect of the additions of broken bottles on hardness and tensile strength in the as-cast condition is given in figures 1-2 and the effect in the age hardened condition at 190^{o}C is given in figures 3-4. The microstructures developed from the as-cast composite and the best composition which is solution treated and aged hardened at 190^{o}C is shown in plate 5

3.2 Discussion

3.2.1 Macro-structural and Micro-structural Analysis

Macro-structural studies revealed a reasonably uniform distribution of glass particles in the aluminum matrix. This was however, not the case in all the compositions. Some compositions had a slight macro-segregation of particles in some places. The glass ceramic particles have a tendency of sintering due to density differences and interactions with the metal. It is therefore a strong function of vitrification and casting temperature effect [5]. The interactions give rise to interfacial bonding the nature of which determines the strength of the composite [4-5].

Plates 1-4 shows the microstructures of the as-cast composite. The microstructure reveals the matrix of aluminum with the reinforcement agents scattered within the grains. The particles are segregated in some areas. This observation agrees with the macrostructure observation of the composite specimens. Plate 5 shows the microstructure of as-cast composite with the highest hardness value which has been aged hardened at 190^{o}C for 5 hours. The microstructure revealed a structure with precipitates distributed within the matrix of the metal. This structure must have resulted because of diffusion and precipitation hardening. Diffusion is rapid at higher temperatures, as the rate of diffusion or the diffusion coefficient, D_d, increases exponentially with temperature according to the Arrhenius-type equation

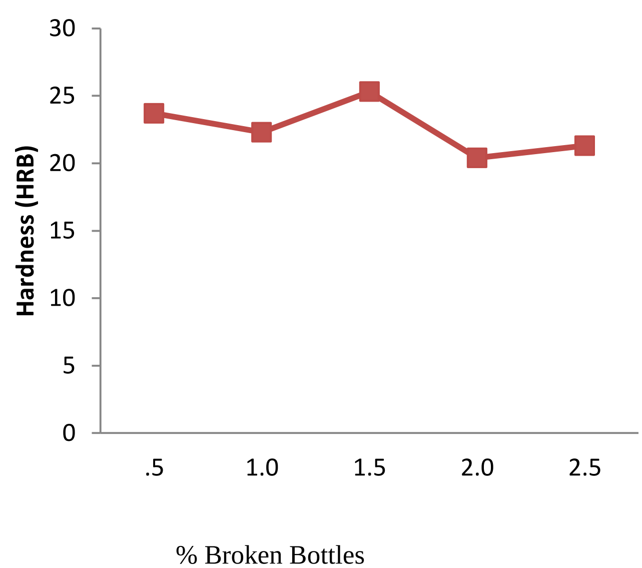

Figure 1: Variation of Hardness with Percentage Addition of Broken Bottles

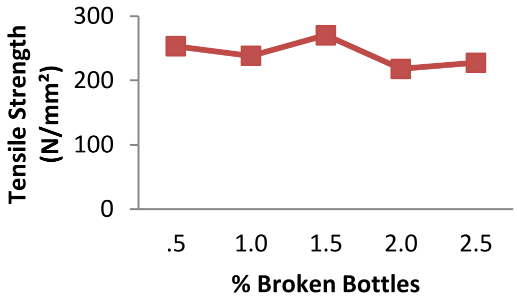

Figure 2: Variation of Tensile Strength with Percentage Addition of Broken Bottles

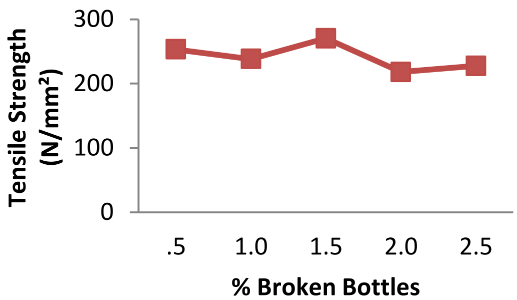

Figure 3: Variation of Hardness on Age Hardening at 190°C for 5 hours of the Best Composition (1.5 % Broken Bottles)

$$D_d = D_o \exp(-Q_d/RT) \quad (1)$$

Where, Q_d is the activation energy for diffusion, D_o is a constant, R is the gas constant and T is the temperature. Temperature has a marked effect on the diffusion coefficient [4]

Plate1: Sample 1 (0.5% glass particulate) As-cast showing the second phase in dendritic solidification in the grains of the Aluminum. X200

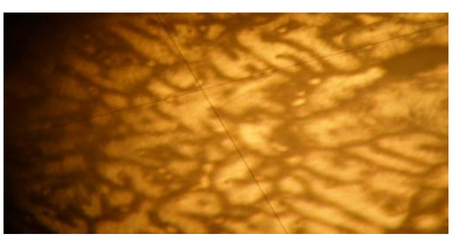

Plate 2: Sample 3 (1.5% glass particulate) As-Cast showing the particulates and dendrites in the Matrix of the Aluminum. X200

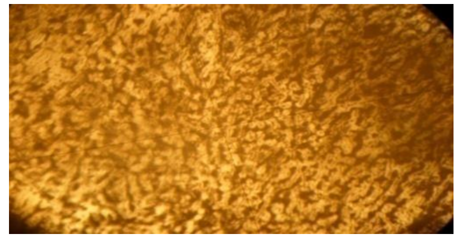

Plate 3: Sample 4 (2.0% glass particulates) As-Cast showing the second phase in dendritic solidification in the Matrix of the Aluminum. X 200

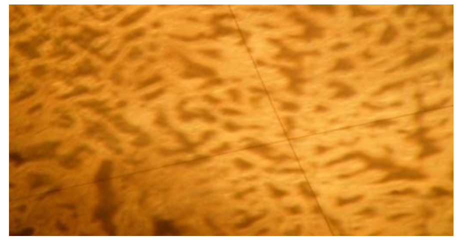

Plate 4: Sample 5 (2.5% glass particles), As-Cast showing dendritic solidification in the Matrix of the Aluminum. X200

Plate 5: sample 3 (1.5% glass particles) showing the age hardened microstructure at 190°C for 5 hours. The black phase is the precipitate and the clear background represents the aluminum matrix. X200

3.3 Hardness Test

Hardness test was carried out on the as-cast composite and the result displayed in Table3. These values were used in plotting the graph of Hardness against percentage additions of reinforcing agents (see fig.1.). The graph showed that 1.5% of the reinforcing agent of the composite had the highest hardness value of 25.3 HRB. The plot did show a consistent trend, the hardness profile was rising and falling from 0.5 -2.5% addition of the reinforcing agent. This may be due to segregation and non-uniform distribution of the reinforcing agent this was observed in the macro and microstructure of the composites. This tends to reduce the hardness values of some of the composites which have higher reinforcing agents. According to Matthews and Rawlings [4] the properties of a composite depend on volume fraction. A generalized form of the equation is

$$X_C = X_m V_m + X_f V_f \quad (2)$$

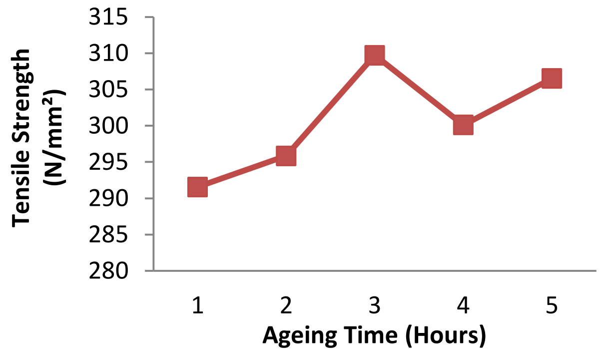

Figure 4: Variation of Hardness on Age Hardening at 190°C for 5 Hours of the Best Composition (1.5% Broken Bottles)

Where, X_C represents an appropriate property of the composite and as before V is the volume fraction and the subscripts m and f refer to the matrix and reinforcement respectively. This equation is known as the law of mixtures.

A common problem encountered during processing is maintaining a uniform distribution of the reinforcement. Ideally, a composite should be homogeneous, or uniform, but this difficult to achieve homogeneity is an important characteristic that determines the extent to which a representative volume of the material may differ in physical and mechanical properties from the average properties of the material. Non-uniformity of the system should be avoided as much as possible because it reduces those properties that are governed by the weakest part of the composite [1, 4].

Other parameters which may significantly affect the properties of a composite are the shape, size, orientation and distribution of the reinforcement and various features of the matrix such as the grain size for polycrystalline matrices. These, together with volume fraction, constitute what is called the microstructure of the composite [1, 4-5]. The above explanations are reasons for which there can be a variation in the true property of a composite.

3.4 Tensile Strength Test

The values of tensile strength test in Table 3 are plotted in fig 2 as tensile strength against percentage additions of glass reinforcements. The plot had the same pattern with that of the hardness against reinforcement additions. This is because hardness values have a relationship with tensile strength. There is that proportionality that exists between tensile strength and hardness values [1, 6]. The same explanation given above in respect of the hardness of the as-cast composite applies to the values of the tensile strength the highest tensile strength occurred in the composite with 1.5% addition of reinforcement. The as-cast composite has a higher tensile strength value in all compositions when compared with the tensile strength of pure aluminum which is 90N/mm^2.

Table 3: Hardness and Tensile Strength Values for As-Cast Composite

Samples	% glass particles	Hardness (HRB)	Tensile Strength (N/mm^2)
1.	0.5	23.7	253.12
2.	1.0	22.3	238.16
3.	1.5	25.3	270.20
4.	2.0	20.4	217.87
5.	2.5	21.3	227.48

Table 4: Age Hardening of Al/ 1.5% glass Reinforced Particulate Composite at 190^{O}C

Ageing Time (Hours)	Hardness (HRB)	Tensile Strength (N/mm^2)
1	27.3	291.56
2.	27.7	295.84
3.	29.0	309.72
4.	28.1	300.11
5.	28.7	306.52

3.5 Aged Hardened Composite

Based on the result of Table3 the composition with highest hardness value and tensile strength was selected and age hardened at 190^{O}C. The result is shown in Table 4 and the data is plotted as figure 3 and 4. Figure 3, which is the plot of hardness against ageing time, showed that the highest hardness value occurred after 3 hours of ageing. Figure 4 is the plot of variation of tensile strength against ageing time. The highest tensile strength also occurred after 3 hours of ageing. This is so because of the relationship between tensile strength and hardness of a material [1]. The values of hardness and tensile strength in Table 4 showed a clear improvement over the as-cast values in Table 3. The same can be said of figures 3 and 4, which exhibit a more consistent pattern of increase than figures 1 and 2. Plate 5 explains this improvement; it is obvious that the composite responded to the age hardening treatment. The microstructure showed the formation of precipitates in the matrix of the metal. The second phases can be clearly seen. Hassan and Aigbodion [7] and Hassan et al [8] had all observed the improvement in mechanical properties as a result of the precipitation of second phase on age hardening of composites in their respective works.

4. CONCLUSION

The study has been concluded and the following conclusions drawn:

- A composite has been developed with aluminum as the matrix and waste bottles and glasses as reinforcement agent.
- The result has shown that waste bottles and glasses which are a serious solid waste can be used in the development of composite material with improved mechanical properties which can be used in machine components.
- The developed composite using waste bottles and glasses had higher hardness and tensile strength. All compositions had tensile strength greater than $90N/mm^2$ which is typical for pure monolithic aluminum.
- The composite responded to age hardening and showed higher values for both hardness and tensile strength as compared to the as-cast values for the same properties.
- The study has shown that waste bottles and glasses can be used as reinforcement agent for aluminum matrix composite in the management of solid waste arising from waste bottles and glasses.

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