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Original Research Article

Stress Stability of Al-Glass/Ceramic Composites

Olutayo W. Abodunrin* and A. K. Musiliyu
Department of Physics, Afe Babalola University, Ado Ekiti, Ekiti State, Nigeria
*Corresponding author E-mail: tayoabodunrin@yahoo.com

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Abstract

The effects of compaction pressure and particle size on the mechanical property of aluminum-glass/ceramic composites are reported in this study. The samples were of cross-sectional area 34.0×35.0 mm^2 with varying thickness 20.8-22.1 mm. A particle size of 26.5 nm was used for glass, ceramic, and aluminum. The samples were made into solids by pressing the materials together at a pressure of 30 MPa. Results showed that ceramic/glass addition and particle size greatly influenced the mechanical stability of the samples. The particle size revealed that samples were noted with stress stability between 0-20 and 40-60 % weights of glass in composites. From the compression test analyses, the maximum strength is in the case of 40 % weight of glass in composites.

Keywords: Mechanical stability, Dynamic stability, Compressive stress, Yield point, Composite

Introduction

Stress stability is the ability of a system to restore itself to an initial stable state after being perturbed. In other words, it is the ability of a system to regain steady state at the moment of any restrain. Stress stability of a compact material could also imply an increase in stress which corresponds to an equal increase in time. In such compact material, the stress/time relationship does not accommodate points of fracture and rupture up to the yield point [1,2]. Stress stability is a mechanical property usually measured in relation to compressive stress. Stress stability is associated with composites, and it is determined from observation of a material's stress–time relationship. The fracture toughness is thus improved from the contribution of stress stability and the maximum compressive strength. A fracture point is a point on the stress-time curve where the sample experiences minor separation into parts under increasing load in a compression test analysis. Stress is also defined as the force or load applied per unit area of the sample. Stress stability or mechanical stability is observed in relation to an increase in stress which has a corresponding increase in the time of the compacted material. The toughness of a material signifies the ability of a material to absorb energy without causing it to break. This implies that metallic-ceramic can absorb much energy before or at the point of breakage of the samples up to the yield point [3,4].

The choice of aluminum (Al) is a result of its strength used in most construction works. Fracture toughness is the ability of the material to resist crack propagation in the material. Ductility is defined as the ability of a material to undergo appreciable plastic deformation before fracture. Ceramic/glass have low ductility [5-7], and the need for reinforcement of a material of high ductility, reasonable wear resistance is considered. This material in composites displays mechanical and structural stabilities, increasing the level at which breakage may be experienced during impact or compression tests [7]. Much is yet to be done in compressive strength by combining metallic elements with ceramics/glass to form composites. Therefore, attention in this study is geared towards determining the stress stability at constant pressure and the same particle size. Moreover, Al-glass/ceramic composites were proposed for industrial and domestic purposes.

Experimental Procedure

The materials used for the study include aluminum powder of purity level 95.50% and sodium silicate liquid obtained from British Drug House (BDH), UK. The tiles and specimen slides were boiled in chromic acid and agitated in trioxoethelene for 30 minutes to remove unwanted particles on their surfaces. Ceramic and glass powders of particle size of 26.5 nm which had earlier been crushed and pulverized before sieving with a mechanical mesh at Center for Energy Research and Development (CERD) in Obafemi Awolowo University, Nigeria was used. The weighing was done with digital weighing balance (Model, BT 200) of sensitivity 0.001 g. Sodium silicate liquid was added in a few drops.

A manual press capable of producing one composite at a time with an average thickness of 21.5 mm and a cross-sectional area of 1,156 mm^2 was used to mold the samples. Formula for mixing in percentage is $Al_{30}Glass_xCeramic_{70-x}$, x = 0, 10, 20, 30, 40, 50, 60, and 70. The grams of aluminum, glass, and ceramic powders were mixed in different ratios to form eight samples. Sodium silicate liquid added was between 12.5-14.5% of Al-glass/ceramic mixture. The mixing was carried out in a mixer for one hour and pressed together at 30 MPa. The samples were subjected to the same moisture condition for four weeks in an open atmosphere in the laboratory. The stress, strain, and other relevant quantities of the samples were measured with a compressive test machine when subjected to loading.

Results

Mechanical properties of Al-glass/ceramic composites

In Table 1, the time has the highest values for 40 % weights of glass in the composites at a pressure of 30 MPa. The stress also has the highest values for 40 % glass weights in the composites of 30 MPa. As for the lowest value, the time was noted at 10 % weights of glass in composites for 30 MPa. The stress has the lowest values at 70 % weights of glass. In addition, the maximum compressive strength of 71.4 MPa at 40 % wt. glass or 30 % wt. ceramic was also recorded, which doubles the two categories of combination, i.e., Al-glass and Al-ceramic.

Table 1 Mechanical properties of samples with the particle size of 26.5 nm at 27 °C, and pressure of 30 MPa

Sample No.	% Al	% Glass	% Ceramic	Compressive Stress (MPa)	Time (s)
1	30	0	70	28.68	95.0
2	30	10	60	32.44	54.0
3	30	20	50	47.28	110.0
4	30	30	40	55.15	120.0
5	30	40	30	71.40	142.0
6	30	50	20	53.60	140.0
7	30	60	10	43.70	88.5
8	30	70	0	25.07	100.0

In Figure 1, the highest point of breakage belongs to $Al_{30}Glass_{40}Ceramic_{30}$. The highest maximum compressive stress noted at 71.4 MPa implies the strength of 30 % weight aluminum 40 % percent weight glass and 30 percent weight ceramic. These curves are smooth with slight kinks at the initial stages. These composites have various categories of stress stability. Some purport the first-class stress stability, and others captured second-class stress stability because of some noticed kinks.

The samples that displayed no kink, no rupture, and no fracture depict first-class candidates of stress stability. This is because of the perfect smooth curve shown without flaws. The ten percent addition of glass in the composites of Figure 1 and also the reduction by the same amount in ceramic composition has shown that the maximum compressive strength has received a slight increase to 32.4 from 28.6 MPa. This was discovered in composites with $Al_{30}Glass_{10}Ceramic_{60}$. The literature review revealed that samples are noted with stress stability at this constant pressure irrespective of various kinks. This might be one of the factors that contributed to the smoothness of the curve. There was an increase in the point of breakage. This has shown a slight difference in the point of breakage of the previous sample $Al_{30}Glass_{0}Ceramic_{70}$.

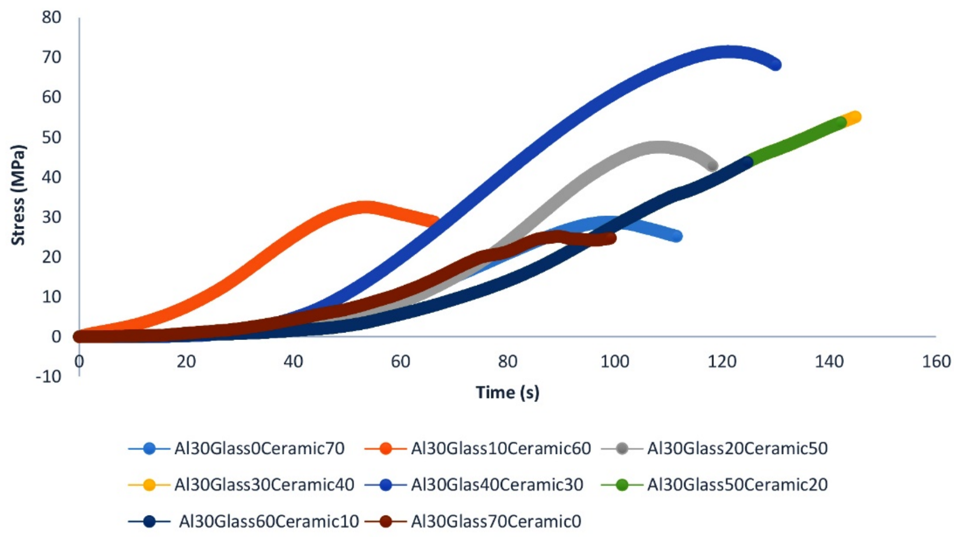

Figure 1 Compressive stress versus time of composites with the particle size of 26.5 nm at 300 bars.

The $Al_{30}Glass_{20}Ceramic_{50}$ composites are known to display the first-class stress stability because of the depiction of smooth curves without any fracture, rupture, or kink propagation. The composite of $Al_{30}Glass_{30}Ceramic_{40}$ has displayed a higher maximum compressive strength and a higher point of breakage. The curve is also in the first-class category of stress stability. One can observe the perfect curve without any trace of flaws. Interestingly, this sample is close to the new sample at a reasonable 40 percent glass and has the highest maximum compressive strength. It can also be shown that the maximum compressive strength and the point of breakage in this first-class category coincide at 55.15 MPa. The curve of this Figure is also known to be in the second-class category of stress stability because of some plasticity regions. One can observe the curve with an elastic limit. Moreover, this sample is very close to the new sample

The sample with $Al_{30}Glass_{40}Ceramic_{30}$ is in the category of second-class stress stability. The curve's starting point up to the point of breakage is smoothly engulfed, but some plastic and elastic regions at the initial stage were embedded in the curve; if not, this smooth display would have been in the first category of stress stability. This has given the impression of a perfect display with the highest point of breakage at 71.4 MPa and the highest maximum compressive strength. The sample is recorded at forty percent weight glass in the composites. The findings have related the preferable combination needed to fabricate or mold any object. The sample with formula $Al_{30}Glass_{40}Ceramic_{30}$ takes the lead in the investigation because it does have fracture or rupture.

The composite of $Al_{30}Glass_{50}Ceramic_{20}$ is in the second-class stress stability division with the point of breakage at 53.6 MPa. The inscription of many plastic regions and kinks along the curve indicate stress stability in the second category. The point of breakage and the maximum compressive strength was found to be reduced from the previous value. The kink is a short depression along the curve, which is minor compared to the fracture or rupture.

The sample of $Al_{30}Glass_{60}Ceramic_{10}$ is also in the second category of stress stability. The strength has dropped from what is being recorded from the described sample of 53.6 MPa to 43.7 MPa. This implies that further increase in glass composition reduces strength and the point of breakage. The trend is showing no further increase in this work.

The sample of $Al_{30}Glass_{70}Ceramic_{0}$ does not show complete stress stability because there is a rupture at the end of the curve. Part of the curve portrays stress stability with the plastic region, while the remaining part towards the end of the curve is noted with stress points and elastic limit. This is a sample of stress Stability in the second category at 25.1 MPa. From the combined samples from Figure 1, there were overlapping of composites $Al_{30}Glass_{0}Ceramic_{70}$, $Al_{30}Glass_{30}Ceramic_{40}$, and $Al_{30}Glass_{50}Ceramic_{20}$.

Maximum compressive stress/time of Al-glass/ceramic composites

Composites were subjected to increasing load, and values of stress were monitored until they reached maximum value. Beyond this point, distortion sets in, which may cause breakage. The relationship between maximum compressive stress and time with the percent weight of glass in the composites at 26.5 nm was contained in the figure above. The results reveal that stress is at its maximum when $Al_{30}Glass_{40}Ceramic_{30}$ with a value of 71.4 MPa gives the highest stress obtainable takes the highest position. The compressive stress increases gradually to the maximum for $Al_{30}Glass_{40}Ceramic_{30}$ and decreases gradually to a minimum for $Al_{30}Glass_{70}Ceramic_{0}$. However, it was noted that at a pressure of 30 MPa, a significant first-class stress stability at 26.5 nm for $Al_{30}Glass_{10}Ceramic_{60}$, $Al_{30}Glass_{20}Ceramic_{50}$ was recorded while $Al_{30}Glass_{30}Ceramic_{40}$, $Al_{30}Glass_{40}Ceramic_{30}$, $Al_{30}Glass_{50}Ceramic_{20}$, and $Al_{30}Glass_{60}Ceramic_{10}$ were observed with second class stress stability. The result reveals that the composites have improved strength due to the nano-particle size of the samples and the constant pressure.

Strength and stress stability of Al-Glass/Ceramic composites

The figure above displayed a pressure value of 30 MPa and 26.5 nm particle size whereby the stress–time relationships were found to be stable over specified ranges, indicating that the materials tend to have stress stability.

The results show that as time increases, the stress gradually increases without rupturing along each of the curves. The increase in time–stress became noticeable for some composites without fracture along the curves. These samples are generally classified as having the stress stability. The variation of stress–time for all samples and their results at 26.5 nm particle size enabled gradual increase in stress–time along the curve with no rupture up to the point of breakage. These are indications of stress stability of the materials just before the point of breakage.

It should be noted that samples that contain points of rupture and fracture do not have stress stability. The sample with stress stability must not display the aforementioned flaws. In other words, samples in the category of stress stability must exhibit a gradual increase in stress–time. The point of breakage may not necessarily coincide with the maximum compressive stress. The samples have different ranges of values for stability in the region of stress stability.

There is an improvement in the composites considered since ordinary glass has maximum compressive stress of 30.32 MPa at particle size of 26.5 nm and pressure of 30 MPa from the literature while Al-glass/ceramic composite in the study has maximum compressive stress of 71.4 MPa at a particle size of 26.5 nm. The implication is that a new composite that can withstand stress up to 71.4 MPa depending on the particle size is obtained. The sample that can stand minimum stress is $Al_{30}glass_{70}ceramic_{0}$, while that for maximum stress is $Al_{30}glass_{40}ceramic_{30}$.

Conclusion

The combination of glass with other ceramics has been noted to generally improve performance in various device applications and utilization. Therefore, the mechanical properties of aluminum of a specific composition could be adjusted for suitable application and utilization with appropriate reinforcement of glass with ceramic.

In this study, Al-glass/ceramic composites were molded by applying compaction pressure using sodium silicate as the binder. The variation in the composition of glass in composites was found to influence the area of the Al-Glass/Ceramic composites for constant pressure. The improved mechanical strength of pure aluminum was obtained from 1.3 MPa of 26.5 nm from the literature to 71.4 MPa, depending on the particle size. In contrast, first-class stress stability is obtained from 10-20 % weight of glass, and second-class category is observed from 30-70 % weight glass in composites at 26.5 nm particle size. The sample was found to have maximum strength for 40 % weight of glass or 30 % weight of ceramic in composites in the compression test analyses.

The material could also be useful for decoration such as flower vases and other household aesthetics. It could also function as a switching device and buffer layer substrate for growing carbon nanotubes.

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