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ARTICLE

Dynamic Stability of Al-Glass/ Ceramic Composites

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Abstract: The effects of compaction pressure and particle size on the mechanical properties of Al-Glass/ ceramic-based samples are reported in this study. The samples were of a cross-sectional area of 34.0 x 35.0 mm^2 with varying thicknesses of 20.8-22.10 mm. The particle size of 26.5 nm was used for glass, ceramic and aluminum powders. 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. Regarding the particle size, it was revealed that the samples were dynamically stable between 0-20 and 40-60 % weights of glass in the composites. The findings showed maximum strength for 40 % weight of glass or 30 % weight of ceramic in composites in the compression test analysis.

Keywords: Pressure, Particle size, Dynamic stability, Compressive stress, Strain, Yield point.

Introduction

Aluminum known for high ductility was reported to have successfully influenced the structural stability of an amorphous material, like glass. The examination of stress–strain relationship showed the smooth display of stress with corresponding strain points. The samples did not accommodate fracture due to rupture along the curve up to the yield point. This was affirmed in the research work [1]. Subsequently, there was a further study into the stress stability of Al-glass composites in which it was recorded that the stress stability has a specific aluminum composition range [2].

The strain uniformity of Al-glass at the nanometer level was also observed at some specific composition ranges of aluminum in composites [3]. The nanoparticle size of choice has a narrow band gap which enhances fast conduction. The pressure of 30 MPa and the particle size in nanometers were reported in the literature to have supported the dynamic stability of iron-ceramic composites and the temperature stability of Al-glass composites [4, 5].

Dynamic 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. Dynamic stability of a compacted material could also imply an increase in stress which corresponds to an equal increase in strain [6]. In such compacted materials, the stress / strain relationship does not accommodate points of fracture and rupture up to the yield point [7]. The fracture toughness is thus improved by the contribution of dynamic stability and maximum compressive strength.

The choice of aluminum is a result of its strength, making it widely used in most construction works. Ceramic/glass has a low ductility [8] with the need for reinforcement by a material of high ductility, particularly when wear resistance is considered. This material in

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composites displays mechanical and structural stabilities, which increases the level at which breakage may be experienced during the impact or compression test. Much is yet to be done in the direction of compressive strength by combining metallic elements with ceramic/glass to form composites. Therefore, attention in this study is geared towards determining the dynamic stability at a constant pressure and same particle size. Moreover, Al-glass/ ceramic composites were proposed for industrial and domestic purposes.

Experimental Procedure

The materials used for this study include aluminum powder of a purity level of 95.50 % and sodium silicate liquid obtained from the British Drug House (BDH), England. 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 a particle size of 26.5 nm, which had earlier been crushed and pulverized before sieving with a mechanical mesh at the Center for Energy Research and Development (CERD) in Obafemi Awolowo University, Ile-Ife, Nigeria, were used. Weighing was carried out with a digital weighing balance (Model BT 200) of a sensitivity of 0.001g. Sodium silicate liquid was added in 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 1156 mm^2 was used for molding the samples. The formula for mixing percentages is $Al_{30}Glass_xCeramic_{70-x}$, X= 0, 10.0, 20.0, 30.0, 40.0...70.0. The aluminum, glass and ceramic powders were mixed together in different ratios to form eight samples. Sodium silicate liquid added was between 12.5 -14.5 % of Al-glass/ceramic mixture. Mixing was carried out in a mixer for one hour and the powders were 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 from CERD.

Results and Discussion

Mechanical Properties of Al-Glass / Ceramic Composites

In Table 1, the strain has the highest value for 10 % weight of glass in the composite at a pressure of 30 MPa. The stress has the highest value for 40 % weights of glass in the composite at a pressure of 30 MPa. As for the lowest value, strain was noted at 60 % weight of glass in the composite for 30 MPa. Stress has the lowest value at 70 % weight of glass. The bulk modulus has the highest value at 30 % weight ceramic or 40 % weight glass in the composites. In Figs. 1-2, the bulk modulus of 30 % wt. Al with 70 % wt. ceramic (O % wt. glass) indicates that Al-ceramic composites have a modulus of 68.26 MPa compared with Al-glass composites with 65.79 MPa, implying substantial differences in bulk moduli. Although the bulk modulus of Al-ceramic composites is lower than in Al-glass composites, yet the maximum compressive strength of $Al_{30}ceramic_{70}$ of 28.78 MPa is higher than the maximum compressive strength of $Al_{30}glass_{70}$ with 24.81 MPa. The combination of Al with glass and ceramic (Al-glass/ceramic) has generated a very high bulk modulus of 137.31 MPa which is twice the value in each case. 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 at room temperature of 27^{o}C, particle size of 26.5 nm and pressure of 30 Mpa.

S/No.	% Al	% Glass	% Ceramic	Compressive Stress (MPa)	Compressive Strain (mm/mm)	Bulk Modulus (MPa)
1		0.00	70.00	28.68	0.42	68.26
2		10.00	60.00	32.44	0.62	52.32
3		20.00	50.00	47.28	0.46	102.78
4	30.00	30.00	40.00	55.15	0.52	106.06
5		40.00	30.00	71.40	0.52	137.31
6		50.00	20.00	53.60	0.60	89.33
7		60.00	10.00	43.70	0.37	118.11
8		70.00	0.00	25.07	0.38	65.97

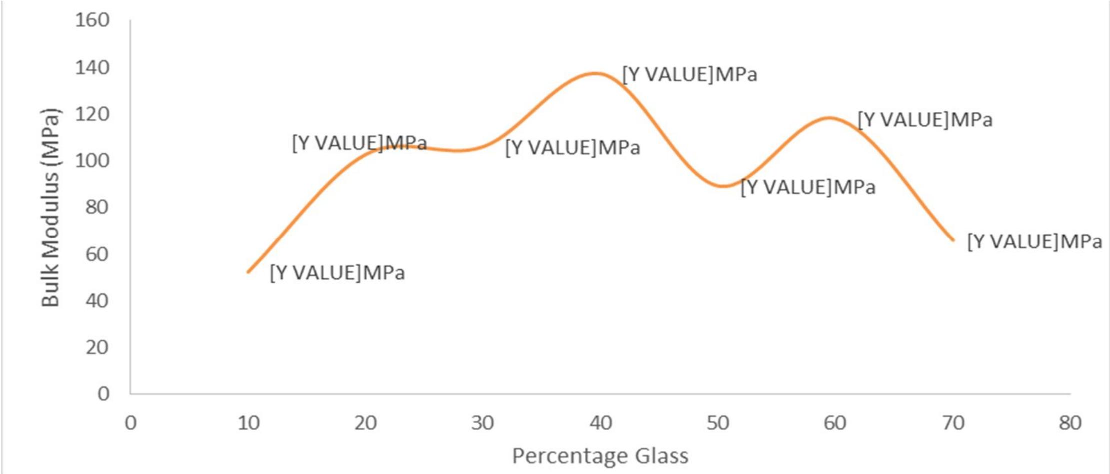

FIG. 1. Bulk modulus *versus* % glass of 26.5 nm at 30 MPa for all samples.

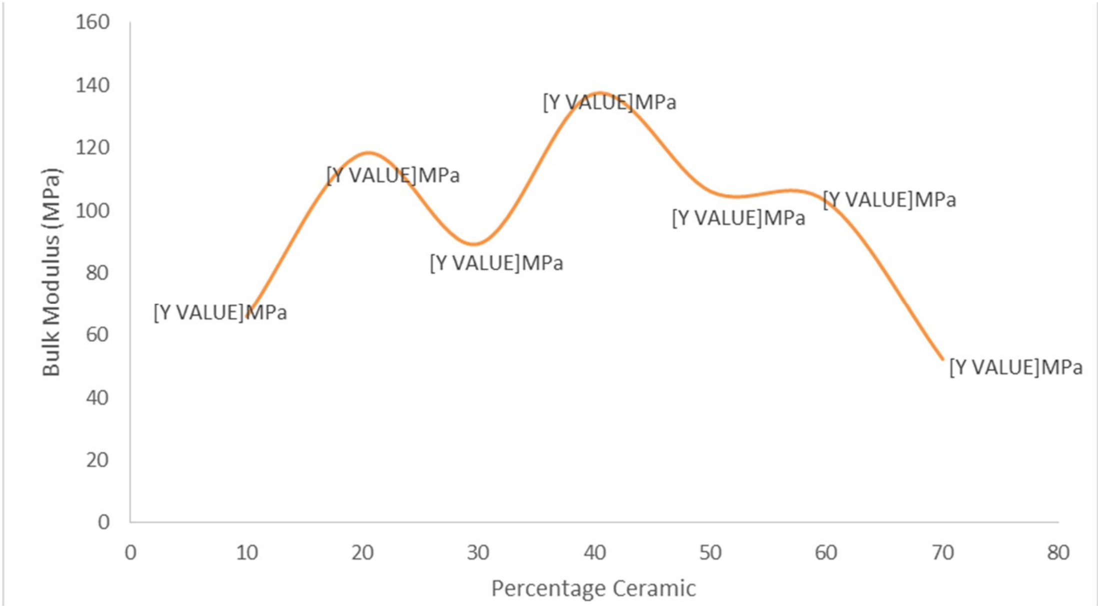

FIG. 2. Bulk modulus *versus* % ceramic of 26.5 nm at 30 MPa for all samples.

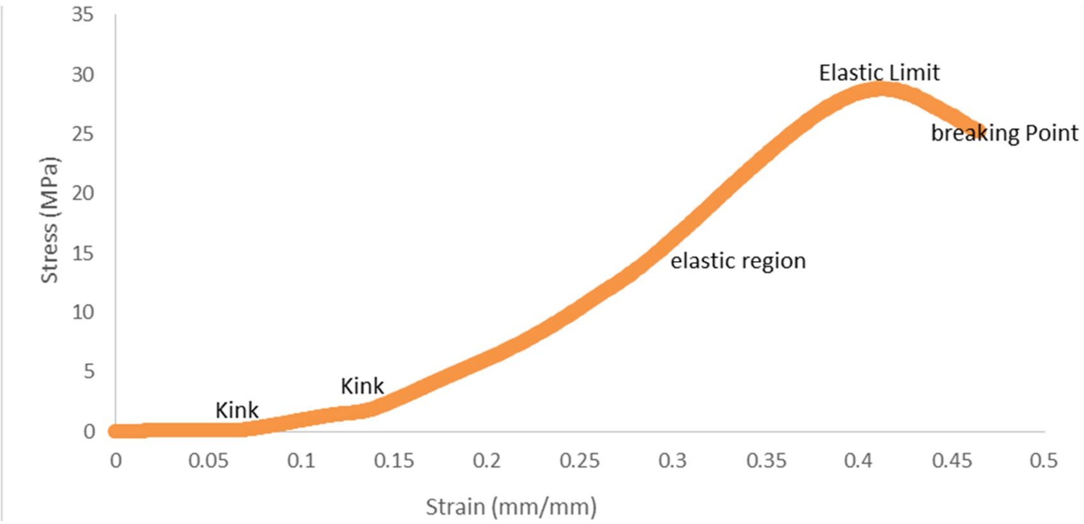

FIG. 3. Compressive stress *versus* strain of 26.5 nm at 30 MPa for $Al_{30}Glass_0Ceramic_{70}$.

The sample in Fig. 3 has its point of breakage at 25.20 Mpa. The maximum compressive stress is also noted at 28.8 Mpa. This implies that the strength of 30 % weight aluminum and 70 % weight ceramic is still low. The curve is smooth with slight kinks at the initial stages. This composite is in one of the categories of dynamic stability. It is in the second class category of dynamic stability because of some noticed kinks.

In Fig. 4, the sample displayed no kinks, no ruptures and no fractures. It is a first-class candidate of dynamic stability. This is because of the perfect smooth curve shown without flaws. The ten-percent addition of glass in the composite of Fig. 3 and the reduction by the same amount in ceramic composition have shown that the maximum compressive strength has received a slight increase to 32.5 Mpa. This was discovered in Fig. 4. From the literature review, it was revealed that samples are noted with dynamic 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 to 28.8 Mpa. This has shown a slight difference compared to the point of breakage of the previous sample of Fig. 3.

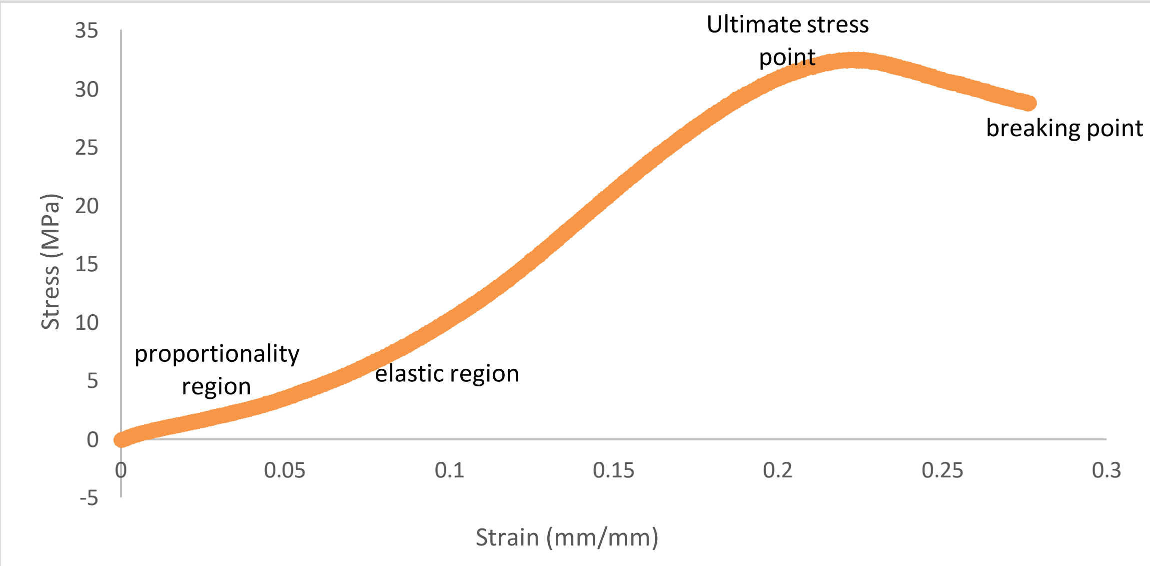

FIG. 4. Compressive stress *versus* strain of 26.5 nm at 30 MPa for $Al_{30}Glass_{10}Ceramic_{60}$.

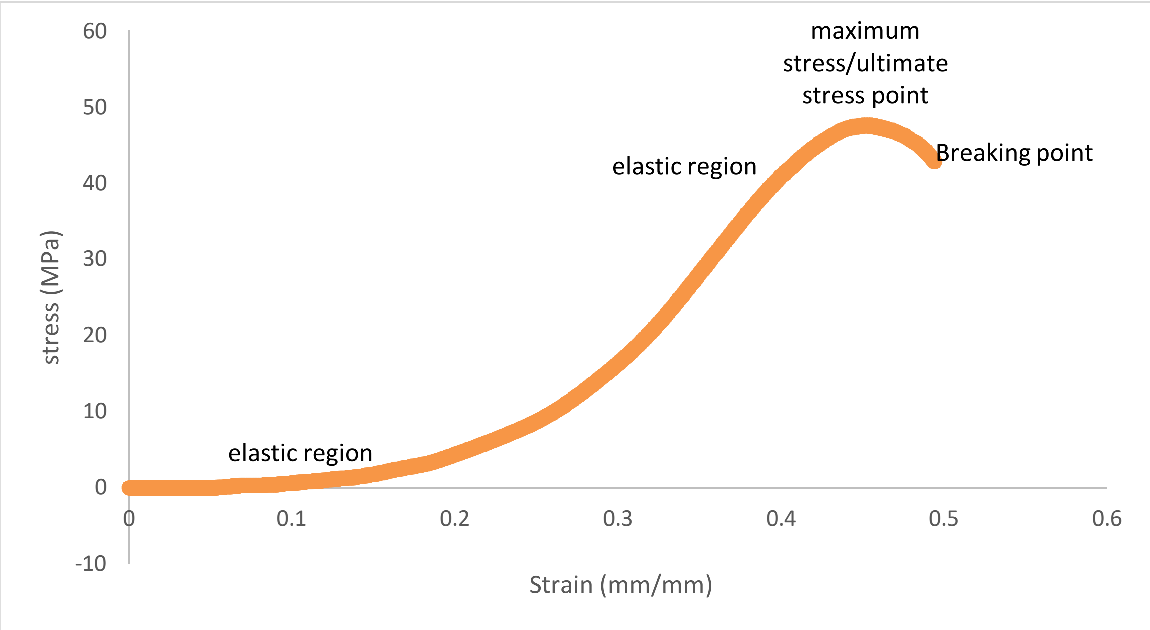

FIG. 5. Compressive stress *versus* strain of 26.5 nm at 30 MPa for $Al_{30}Glass_{20}Ceramic_{50}$.

The composite of Fig. 5 has displayed a higher maximum compressive strength and a higher point of breakage. The curve of this Figure is also known to be in the first-class category of dynamic stability. One can observe the perfect curve without any trace of flaws. Interestingly, this sample is close to the new sample at a reasonable low percentage of glass, but with the highest maximum compressive strength.

In Fig. 6, it has been shown that the maximum compressive strength and the point of breakage coincide at 55.15 MPa. The curve of this Figure is also known to be in the second-class category of dynamic stability because of some regions of plasticity. One can observe the curve with an elastic limit. Moreover, this sample is very close to the new sample at equal percentage of glass or ceramic, but with the highest maximum compressive strength of 71.4 MPa and the highest point of breakage of 68.2 MPa.

Fig. 7 is in the category of second class of dynamic stability. The starting point of the curve to the point of breakage is smoothly captured, but some plastic and elastic regions at the initial stage were embedded in the curve if this smooth display would not have been in the first category of dynamic stability. This has given the impression of a perfect display with the highest point of breakage and the highest maximum compressive strength. The sample is recorded at forty percent weight glass in the composite. The findings have related the preferable combination needed to fabricate or mold any object. The sample with the formula $Al_{30}Glass_{40}Ceramic_{30}$ takes the lead in the investigation carried out, because it does not have fractures or ruptures.

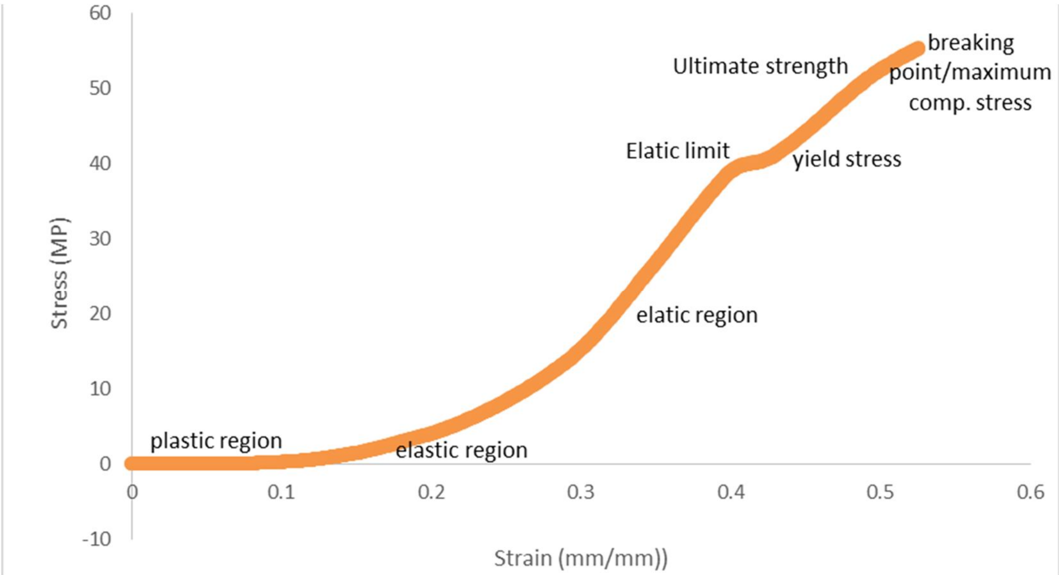

FIG. 6. Compressive stress *versus* strain of 26.5 nm at 30 MPa for $Al_{30}Glass_{30}Ceramic_{40}$.

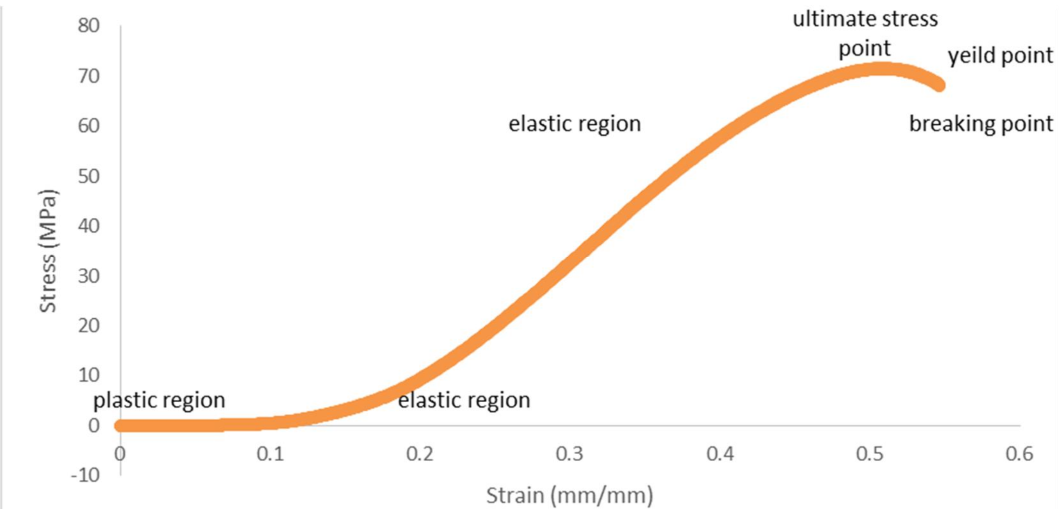

FIG. 7. Compressive stress *versus* strain of 26.5 nm at 30 MPa for $Al_{30}Glass_{40}Ceramic_{30}$.

The composite in Fig. 8 is in the division of the second class of dynamic stability. The inscriptions of many plastic regions and kinks along the curve are indications of dynamic stability in the second category. The point of breakage and the maximum compressive strength were found to be reduced compared to the previous values. The kink is a short depression along the curve which is minor compared to the fracture or rupture.

The sample in Fig. 9 is also in the second category of dynamic stability. The strength has dropped from what is being recorded from the latter figure to 43.7 MPa. This implies that further increase in glass reduces both the strength and the point of breakage. The trend is showing no further increase in this work.

The sample of Fig. 10 does not show the complete dynamic stability, because at the end of the curve, there is rupture. Part of the curve portrays the dynamic stability in the plastic region, while the remaining part towards the end of the curve is noted with stress point and elastic limit. This is a sample of dynamic stability in the second category.

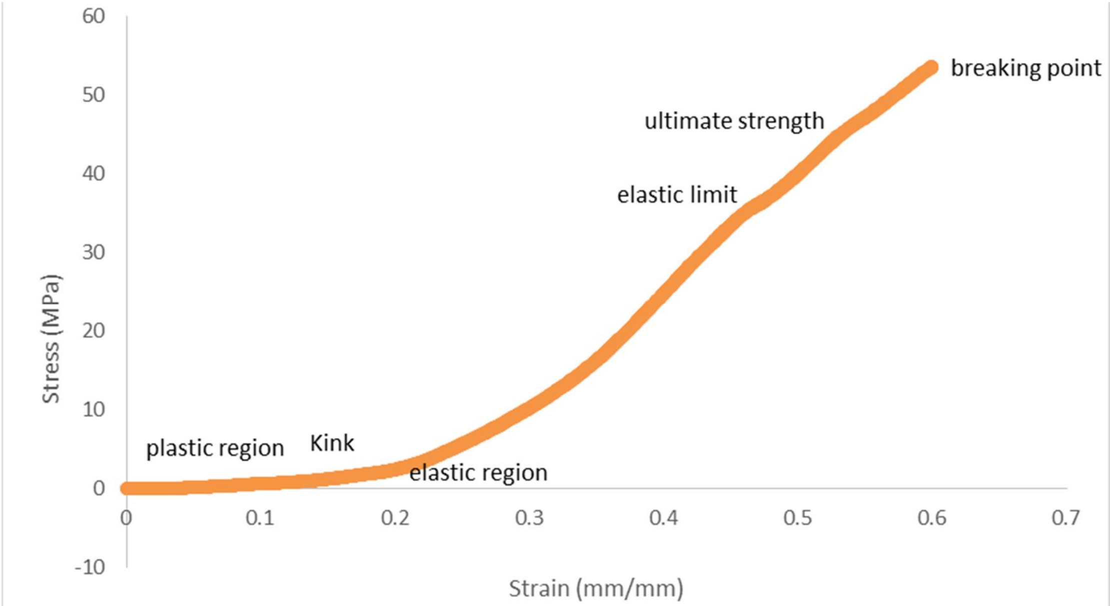

FIG. 8. Compressive stress *versus* strain of 26.5 nm at 30 MPa for $Al_{30}Glass_{50}Ceramic_{20}$.

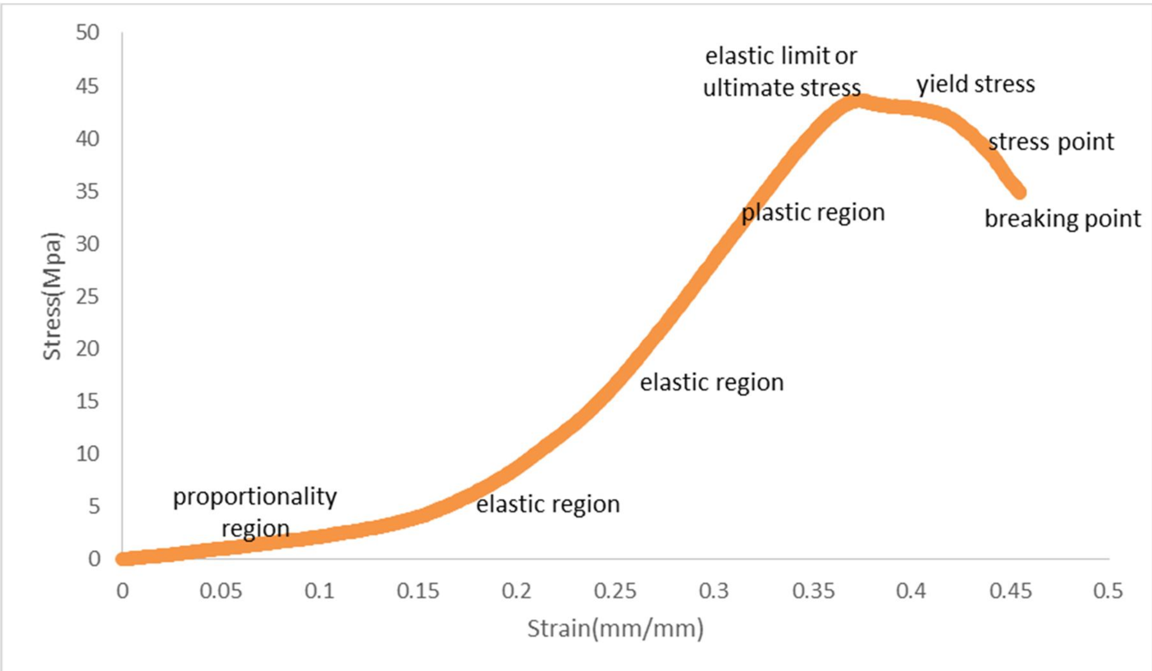

FIG. 9. Compressive stress *versus* strain of 26.5 nm at 30 MPa for $Al_{30}Glass_{60}Ceramic_{10}$.

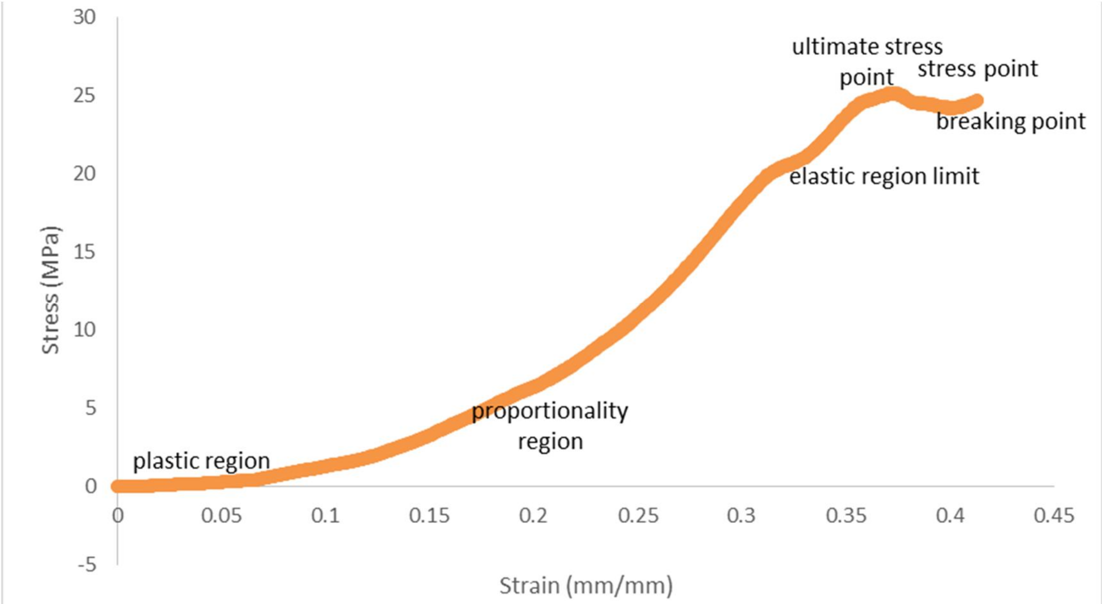

FIG. 10. Compressive stress *versus* strain of 26.5 nm at 30 MPa for $Al_{30}Glass_{70}Ceramic_{0}$.

Maximum Compressive Stress / Strain of Al-Glass / Ceramic Composites

Composites were subjected to increasing load and the values of stress monitored until reaching the maximum value. Beyond this point, distortion sets, which may cause breakage. The relationships between maximum compressive stress and strain and percent weight of glass in the composites at 26.5 nm are shown in Figs. 3 – 10. The results reveal that stress is at its maximum in the case of $Al_{30}Glass_{40}Ceramic_{30}$ with a value of 71.4 MPa, which gives the highest stress obtainable. The compressive stress increases gradually to maximum for $Al_{30}Glass_{40}Ceramic_{30}$ and further decreases gradually to minimum for $Al_{30}Glass_{70}Ceramic_{0}$. It was noted however that at a pressure of 30 MPa, a significant first-class dynamic stability at 26.5 nm for $Al_{30}Glass_{10}Ceramic_{60}$ and $Al_{30}Glass_{20}Ceramic_{50}$ 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 dynamic stability. The results reveal that the Al-Glass/Ceramic composites have improved strength as a result of the nano-particle size of the samples and the constant pressure.

Strength and Dynamic Stability of Al-Glass/Ceramic Composites

Figs. 3 - 10 display a pressure value of 30 MPa and 26.5 nm particle size, whereby the stress–strain relationships were found to be stable over specified ranges, indicating that the materials have the tendency of having dynamic stability.

The results show that as the strain increases, the stress increases gradually without rupture along each of the curves. The increase in strain - stress became noticeable for these composites without fracture along the curves. All these samples are generally classified as being dynamically stable. The variation of stress - strain / time for all samples and their results at 26.5 nm particle size depicts gradual increase in stress - strain along the curve with no ruptures up to the point of breakage. These are indications of dynamic 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 dynamic stability. Samples with dynamic stability must not display the above mentioned flaws. In other words, samples in the category of dynamic stability must exhibit a gradual increase in stress - strain with 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 dynamic stability.

There is an improvement in the composites considered, since ordinary glass has a maximum compressive stress of 30.32 MPa at a particle size of 26.5 nm and a pressure of 30 MPa from the literature, while Al-glass/ceramic composites in the current study have a maximum compressive stress of 71.4 MPa at a particle size of 26.5 nm. The implication of this 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 withstand 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 ceramic had been noted to generally improve the performance in various device applications and utilizations. 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 composition of glass in composites was found to influence the area of the Al-glass/ceramic composites for constant pressure. Improved mechanical strength of pure aluminum from 1.3 MPa of 26.5 nm from the literature to 71.4 MPa depending on the particle size was obtained, while first-class dynamic 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 analysis.

The material obtained could also be useful for decoration, such as flower vase, and other house hold aesthetics.

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