Experimental analysis of energy absorption behaviour of Al-tube filled with pumice lightweight concrete under axial loading condition

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Abstract. This Paper aimed at experimental investigation of compressive behaviour of square tube filled with pumice lightweight concrete (PLC). Square section of 20×20×30 mm is investigated, which is the backbone structure. The compression deformation result shows the better folding mechanism, displacement value, and energy absorption. PLC concrete filled with aluminium thin-wall tubes has been revealed superior energy absorption capacity (EAC) under low strain rate at room temperature. Superior EAC resulted as a result of mutual deformation benefit between aluminium section and PLC is also analysed. PLC was characterised by Fourier Transform Infrared (FTIR) and Field Emission Scanning Electron Microscopy (FE-SEM), and Energy Dispersive X-ray Spectrometry (EDX) analysis for better understanding of material behaviour. Individual and comparative load bearing graphs is logged for better prospective of analysing. Novel approach aimed at validation of porous lightweight concrete for better lightweight EA filler material.

1. Introduction
With emerging engineering there always a thirst of structure with better load bearing and effectiveness. This craving has led to many noteworthy structural developments. When it comes to on field application, there arise constraints like space, weight, chemical action, availability and cost. Latest development is towards hollow backbone metal section with filler material as internal matrix to have better energy absorption. Along with that it should have the advantage of being cheap, light weight, easy to manufacture and are able to sustain a impacts with constant loading before failure i.e. it should give predictable failure mechanism. Jailania and Othman[1] made same approach for the aluminium alloy extrusion with filler material for better energy absorption, which is accomplished by using polystyrene foam. Mechanically polystyrene foam is clear, hard and brittle. It is inexpensive resin and moulded into any shapes i.e. great from manufacturing point of view. Dynamic impact for axial crushing of aluminium alloy-6061 square tube section filled with polystyrene foam showed decay modes i.e. diamond compound symmetry, axisymmetric concertina mode of formation and mixing
times which is, observed as predictable and consistent. Deformation behaviour of the aluminium extrusion is not affected by polystyrene filler.

Houet al [2] reviewed development of concrete-filled steel tubular structures (CFST/CFDST). Concrete and metal tubes functioned mutually, hence enhancing load bearing axially. CFST uses normal weight concrete which is heavy in weight and gets affected by seismic hazards. So porous material is getting its way towards energy absorbing structures for being privileged with light weight and gradually collapsing cell walls. Rajak et al [3] metal foams/ Al-foams are already in some special purpose application due to its cost. It’s having huge potential but cost limits its usability. Novel idea regarding application of pumice lightweight concrete is introduced, and investigation is carried out on comparative load deformation behaviour of PLC filled and unfilled aluminium sections (20×20×30) mm. Glok et al [4] pumice lightweight concrete with decent weight to strength ratio. Pumice is a naturally occurring porous stone which normally come into existence out of volcanic eruption. It is amorphous and chemically inert. Taherisharghe et al [5] recent structural engineering application as aggregate additive fibre dispersive medium, and Hossain[6] light weight shock absorbing cement inspires a step forward towards lightweight filled section with better load bearing. In this present paper, experimental validation is carried by “Comparative compressive test on pumice filled (FT) and unfilled section (UT)”. Load deformation data is observed and graphically analysed.

2. Material and Methods

2.1. Sample preparation

The sample preparation for the compressive test requires two materials which are to be combined – Aluminium section and Pumice stone. Filled and unfilled sections are made in two sets containing 12 each. Rajak et al [7] aluminium extrusion section of cross section 20×20 is taken and 24 samples is fabricated precisely by using power hacksaw each of length 30mm. Pumice is fabricated by the help of abrasive slow cut wire, 12 samples each for filling and individual testing. Structural epoxy is used to reinforce PLC inside the metal section. Proper solidification time confirms strong bond between metal section and PLC, prepared samples are shown in the figure 1. Table 1 shows the nominal dimensions of prepared samples before compression test.
Table 1: Nominal dimension of unfilled and filled sections

| Sample No. | Height (mm) | Thickness (mm) | Cross-sectional area (mm²) | Mass (Unfilled) (gm) | Mass (Filled) (gm) |
|------------|-------------|----------------|----------------------------|----------------------|-------------------|
| 1          | 30          | 0.96           | 73.1136                    | 11.4395              | 16.6993           |
| 2          | 30          | 0.96           | 73.1136                    | 11.1100              | 17.5546           |
| 3          | 30          | 0.96           | 73.1136                    | 10.6864              | 16.4820           |
| 4          | 30          | 0.96           | 73.1136                    | 10.7369              | 16.9734           |
| 5          | 30          | 0.96           | 73.1136                    | 11.2515              | 16.6806           |
| 6          | 30          | 0.96           | 73.1136                    | 10.8472              | 16.8862           |
| 7          | 30          | 0.96           | 73.1136                    | 10.7373              | 16.5666           |
| 8          | 30          | 0.96           | 73.1136                    | 10.1903              | 17.5619           |
| 9          | 30          | 0.96           | 73.1136                    | 10.7976              | 16.8687           |
| 10         | 30          | 0.96           | 73.1136                    | 10.8217              | 16.6048           |
| 11         | 30          | 0.96           | 73.1136                    | 11.6796              | 16.4603           |
| 12         | 30          | 0.96           | 73.1136                    | 10.6935              | 17.6422           |

2.2 Density measurement

Density of individual set of samples is noted and analysed to get the variation range of each. Test sample density fall in the range of 0.0004037 to 0.0005315 g/mm³ for PS, 0.004646 to 0.005325 g/mm³ for UT and 0.001372 to 0.0147 g/mm³ for FT.

3. Results and Discussion

3.1 Microstructure analysis

Detailed topographic study carried out through FE-SEM, figure 2 shows 220X magnified image of the highly porous surface of pumice particles. Pores formed due to pressure differential occurrence during volcanic eruption along with sudden cooling. Depending upon the final solidification state, tubular or spherical are the two pore orientation formed. Tubular form is seen to be predominant in nature, but the mechanical properties are observed to be anisotropic. Othmanet al [8] and Sayadi et al [9]this
novel approach, pumice with internal spherical orientation is considered for compressive test. Pumice being non-conductive is plated with platinum with the help of compact rotary pumped coating system.

Figures 3 shows the wall thickness in microns.

3.2 EDX and FTIR spectroscopy

Pumice is known amorphous solid generally chemically inert in nature PLC when tested for compression individually, showed failure due to mixing tendency of shear failure and collapsing cell wall. Average load bearing on individual testing of 12 precisely machined PS sample is found to be 852.70N.

Table 2: Chemical composition of pumice stone after EDX

|   | O  | Na | Al  | Si  | S   | K   | Ca | Fe  |
|---|----|----|-----|-----|-----|-----|----|-----|
|   | 60.82 | 1.58 | 5.93 | 11.78 | 1.82 | 2.38 | 13.83 | 1.86 |

An Energy Dispersive X-Ray Spectroscopy (EDS) determined the chemical composition of the coated pumice elements with their respective proportions. EDX spectroscopy considered at 3 iterative points and similar chemical constituent is observed in Table 2. EDX is significant as consistency in the constituent element under test is concerned. Spectrum analysis as in figure 4, at different point of PLC sample is seen to be normal with little variation in weight%.

Figure 2. FE-SEM micrograph of pumice stone with 220X magnification illustrating pore orientation

Figure 3. FE-SEM micrograph of PS with 400X magnification plotting wall thickness

Figure 4. EDX spectrum of chemical composition of pumice stone

Figure 5. FTIR characterization
One of the most effective means to find about the basic and important chemical bonds is through Fourier Transform Infrared Spectroscopy (FTIR). All the peaks are assigned in the FTIR spectrum as shown in the figure 5. Peaks are detected at position around 1081 cm$^{-1}$, 1437 cm$^{-1}$, 1653 cm$^{-1}$, 2921 cm$^{-1}$ and 3428 cm$^{-1}$ which shows =C-H bend, aromatic C=C bending, aldehyde C=O stretch, X-H stretch and O-H stretch, respectively. Indication of organic and inorganic bonding confirms it as a composite material.

3.3 Compression test

Compression test has done for comparative study of 30mm length extruded aluminium section (20×20) mm sections filled and unfilled. It is noted that the low strain deformation is recorded. Each sample deformed to 60% of its original length i.e. section plastically deformed for 18mm. Limit load or maximum bearing load is carefully noted for each sample, for theoretical understanding this deformation mechanism is a case of large deformation where elastic deformation is neglected. Table 1 shows the nominal dimensions of filled and unfilled sections. Figure 6 shows graphical presentation of comparative energy absorption and consistency.

Experimentally it is witnessed for each sample that metal section follows regular deformation mechanism, no sample is seen to go out of general deformation pattern. During the whole sample testing no sample faced unpredictable buckling failure. So it is noted that pumice has not affected the deformation pattern of aluminium section. Figure 7 shows the comparative collapse pattern that validates the same. As load bearing is concerned, when pumice and aluminium extrusion section tested individually, it is observed that both inward and outward buckling is found in the aluminium tube, and the PLC stub column exhibited shear failure in a crushing fashion. PLC stub and aluminium tube average force bearing recorded as 852N and 3519N respectively as in figure 8. Mutual load bearing assumed to be summed up force bearing value of both individual section, but recorded value for pumice-encased aluminium tubes showed enhanced load bearing considerable more than assumed value.
4. Conclusions

From the following experimental analysis, it can be concluded that Pumice lightweight concrete enhances load bearing when compared to hollow section of same dimension. After having 60% deformation folding pattern remained same for both filled and unfilled section. Decay modes observed to be diamond compound symmetry, axisymmetric concertina mode of formation and mixing times which is well said to be predictable and consistent. Relative mass mean load level has been improved considerably by filling the tubular member with PLC, which is been confirmed by test element models. Load bearing is enhanced considerably than the assumed value due to mutual structural benefit. Aluminium tube constrained the PLC stub, resisting it to undergo shear and crushing failure. Gradual crushing cell wall of PLC facilitated aluminium tubes for enhanced load bearing.

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