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Effect of arctic environment on flexural behavior of fly ash cenosphere reinforced epoxy syntactic foams

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ABSTRACT

In this paper, the effect of arctic conditions on the flexural response of cenosphere/epoxy syntactic foams is investigated. Understanding the behavior of such foams under extreme conditions is critical for exploring their suitability for constructing lightweight platforms used in arctic explorations. Such platforms are exposed to subzero temperatures for extended periods of time potentially degrading their mechanical properties. In the research study presented here, samples of cenosphere/epoxy syntactic foams were conditioned under arctic environment at −60 °C temperature for a period of 57 days. Flexural tests were then conducted at room temperature as well as in-situ −60 °C on the conditioned samples and compared against unconditioned samples. Combinations of surface modification and cenosphere volume fractions were considered. Experimental findings showed that an increase in flexural modulus can be observed at room temperature with increasing cenosphere volume content for both untreated and treated cenosphere reinforced syntactic foams. In contrast, a decrease in flexural strength was observed as compared to neat resin. For the case of arctic exposed samples, an apparent increase in flexural modulus was recorded between 7-15% as compared to room temperature cenospheres/epoxy syntactic foams. In addition, an apparent increase of 3–80% in the flexural strength was observed under arctic environment. The conditioning of cenosphere/epoxy syntactic foams under low temperatures manifested lower strains to failure as compared to neat epoxy and they exhibit quasi-brittle behavior leading to sudden failure in the post peak regime.

1. Introduction

Sandwich composites with foam cores are of interest in applications like aircraft and naval applications. These foam cores are typically made from closed-cell and low-density polymers and are sandwiched between fiber-reinforced polymeric composite facesheets. Such sandwich constructions are extremely lightweight, which increase the buoyancy of the ship-structures. However, extended period of exposure to sea environment in marine applications often results in mechanical property degradation due to moisture absorption and temperature variations in these materials. Structural components in arctic marine applications encounter these major concerns and are the focus of the present work. Dispersion of hollow microballoons/microspheres in resin matrix forms a special class of composite known by name syntactic foams [1,2]. The spectrum of engineering applications of these foams is very broad as elaborately discussed by Gupta et al. [3–5]. Components like boat decks, ribs, hulls and floatation modules are some of the widely known and proven applications in naval structures. Nevertheless, syntactic foams are also utilized in remotely or humanly operated vehicles used for sea explorations. These closed cell foams are also promising material systems in pipelines laid deep in sea demanding thermal insulation [6].

Developing structure-property correlations and understanding failure mechanisms therein in tailoring syntactic foam properties for various applications has been extensively dealt with in the past decade [7–10]. Thermal and electrical behavior of syntactic foams [11–14] have also been investigated in addition to mechanical properties. Further, syntactic foams reinforced with micro and nano scale fillers (fiber and particle) have been studied extensively, which were beneficial towards tailoring the properties as compared to plain syntactic foams [15,16]. Recently thermoplastic foams have been developed using industrial scale injection molding machine [17–23], compression molding [24], 3D printing [4,5] and characterized for mechanical properties. These closed cell foams are tested under 3 point bending in flexural

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[25–28] or with short beam test condition [29–31] in recent past. The relationship of volume fraction and reinforcement surface treatment with the modulus in flexure is often complex. Relative modulus of the particle material, geometrical parameters and the matrix properties are influenced by the matrix stiffening due to lower density hollow microballoons. Effect of particle shell thickness and interfacial bonding between the constituents also have significant influence on the flexural properties. Published literature reports several experimental and analytical studies on hygrothermal effects [32–34], impact loading [35], microstructural characterization [36,37] and polymer cure cycle effect [38] of syntactic foams. Variations in cenosphere shell thickness and built-in porosities therein makes structure-property correlations of cenosphere embedded thermosetting foams quite complex and challenging to address especially with additional temperature effects like in arctic conditions. Marine vessels are often subjected to arctic conditions. Understanding mechanical behavior in arctic scenario is necessary and demanding as these naval structures are made of syntactic foams. Further, overall mechanical behavior and water uptake is significantly governed by operating temperatures [39,40] particularly in arctic condition wherein low temperature prevail.

Engineered glass microballoons and fly ash cenospheres as filler materials have been widely studied [14,41]. Degradation of glass microballoons syntactic foams has been reported recently due to dealkalization of glass [42]. Fly ash is a potential environmental pollutant and an industrial waste comprising of hollow cenosphere particles that are made of alumina and silica primarily. These hollow microballoons are by-product of coal combustion in thermal power plants. Though, they have numerous defects on and in their walls with marginal deviations from perfect sphericity, the alumino-silicate composition might compensate the limitations caused by such defects. Further, fly ash cenosphere properties have been found to be in the range of widely used glass microspheres. Developing utilitarian syntactic foams with such industrial waste can help the environment, minimize landfill burden and create foams with better properties [43–45]. The current work uses fly ash cenospheres for manufacturing syntactic foams.

Majority of studies on the mechanical property characterization of syntactic foams is conducted at room temperature (RT) [46,47]. However, for marine vessels for operation in the arctic or antarctic oceans, it is critical to investigate these materials in such harsh conditions of subzero temperatures. The effect of arctic environment on cenosphere/epoxy foams has not been studied before, and is crucial for marine structural components operating in Arctic regions. The present study explores this possibility by investigating the flexure behavior of syntactic foams owing to changes in operating temperatures. Hollow fly ash cenospheres, epoxy matrix, filler treatment and filler loading are held constant while altering the exposed temperatures. Thereby, changes in the fracture pattern are governed by temperature variations. The behavior of syntactic foams in such temperatures can be explored by such an investigation, which has not been reported in the literature yet. Present work focuses on the development of environment friendly syntactic foams subjected to arctic conditions along with the influence of filler (cenosphere) surface modification.

2. Sample preparation and test method

2.1. Sample preparation

CIL 150 grade cenospheres are procured from Cenosphere India Ltd., Kolkata and their basic properties are presented in Table 1 [48]. Lapox is used as matrix (L-12 grade, K-6 hardener) and is bought from Atul, Valsad, Gujarat. Two configurations of cenosphere/epoxy foams are prepared in the present work i.e. with cenospheres in as received condition and their surface modified counterparts. Surface treatment procedure and the confirmatory tests of silane coating are outlined in Ref. [49]. The built-in void space within cenospheres, volume fraction and size play a critical role in lowering the material density substantially. Further, interfacial adhesion owing to surface modification of cenosphere promotes effective load transfer mechanisms between the constituents [50]. It's interesting to analyses the effect of arctic temperature on the interface and if it could sustain the integrity under such lower operating temperatures. Cenospheres in desired proportion are dispersed gently in epoxy resin until homogenous slurry is formed. Hardener is added by 10 wt % to initiate polymerisation and further stirred for 2 more minutes, degassed for 5 min and finally poured in the aluminium molds. Curing time of 24 h and post curing at 90 °C for 3 h is adopted. Syntactic foams with cenosphere variation of 20, 40 and 60 vol %, both in as received and surface modified conditions are prepared having dimensions as outlined in ASTM D790. Neat epoxy samples are also casted by following similar procedure for comparative analysis. At least five specimens each are tested in flexure under room and arctic temperatures. Samples are coded as per the EXX-Y convention where epoxy, cenosphere content and filler surface treatment is represented by letters E, XX and Y (U - Untreated, T - treated) respectively. Experimental density of all the samples is estimated using ASTM D792-08. Rule of mixture is used to compute theoretical density and is given by,

Table 1
Chemical, physical and sieve analysis details of cenospheres[a] [48].

Physical properties		Chemical analysis		Sieve analysis	
True particle density	920 kg/m^3	SiO_2	52–62%	+30# (500 μm)	Nil
Bulk density	400–450 kg/m^3	Al_2O_3	32–36%	+60# (250 μm)	Nil
Hardness (MOH)	5–6	CaO	0.1–0.5%	+100# (150 μm)	Nil
Compressive strength	180–280 kg/m^3	Fe_2O_3	1–3%	+150# (106 μm)	0–6%
Shape	Spherical	TiO_2	0.8–1.3%	+240# (63 μm)	70–95%
Packing factor	60–65%	MgO	1–2.5%	- 240#	0–30%
Wall thickness	5–10% of shell dia.	Na_2O	0.2–0.6%		
Color	Light grey – light buff	K_2O	1.2–3.2%		
Melting point	1200–1300 °C	CO_2	70%		
pH in water	6–7	N_2	30%		
Moisture	0.5% max.				
Loss on ignition	2% max.				
Sinkers	5% max.				
Oil absorption	16–18 g/100 g				

[a] As specified by supplier.

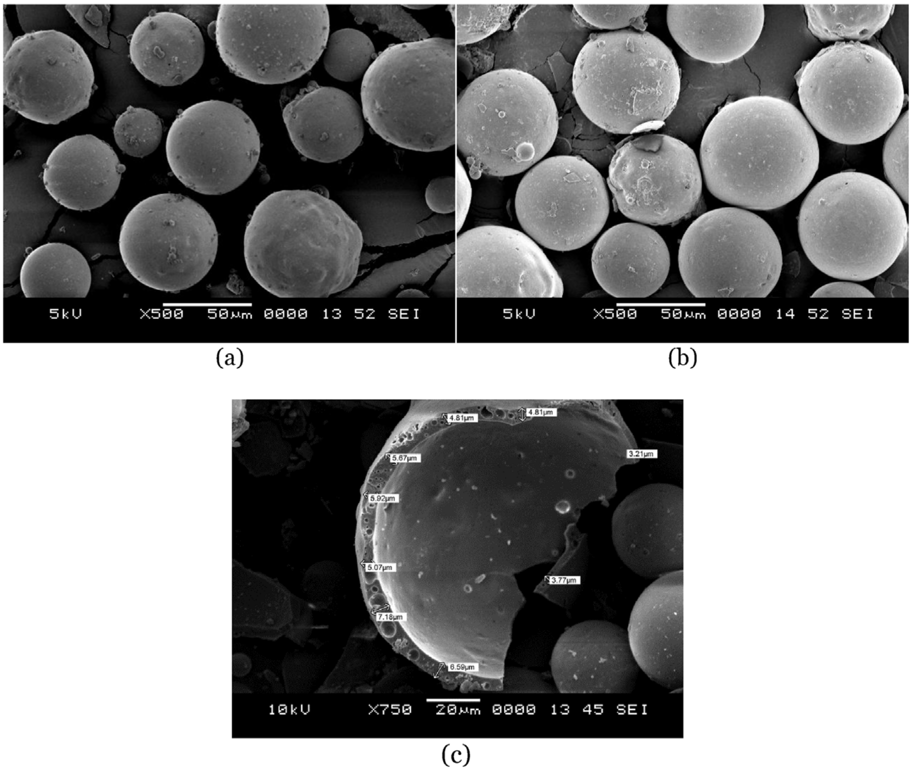
$$\rho_c = \rho_f V_f + \rho_m V_m \tag{1}$$

where, ρ, V, c, f and m denote density, volume fraction, composite, filler and matrix respectively. Experimental (ρ^{exp}) and theoretical (ρ^{th}) densities are utilized further to calculate void volume % (ϕ_V) and is given by Refs. [9,26],

$$\phi_V = \frac{\rho^{th} - \rho^{exp}}{\rho^{th}} \tag{2}$$

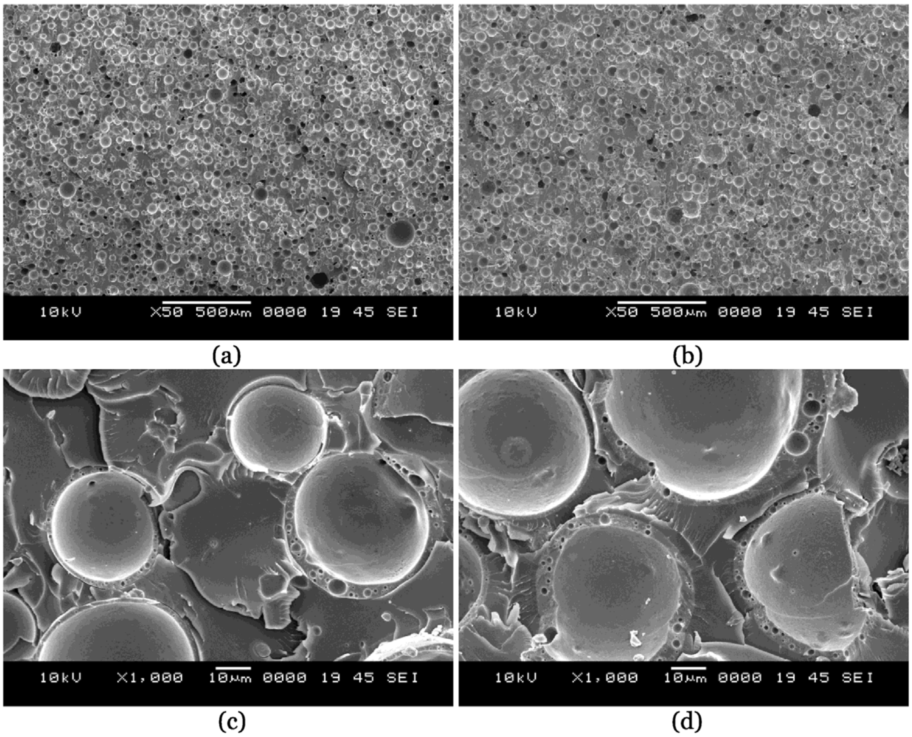
2.2. Arctic conditioning and flexure test

All the samples prepared are conditioned in accordance to ASTM C272 and D5229 standards as there are no standards available for arctic tests. Specimens are dried at 100 °C prior to conditioning. As part of arctic conditioning, all the samples are maintained at −60 °C (Thermo Scientific TSU Series −86 °C Upright Ultra-Low Temperature Freezer) for 57 days. Post arctic conditioning, all the samples are tested at −60 °C in-situ. Flexure test is conducted as per ASTM D790 standard at both room (30 °C) and arctic condition (−60 °C) using Instron 5969 Tabletop UTM. Crosshead displacement is maintained constant at 1.4 mm/min. Flexural strength and modulus of elasticity in flexure is



(a) (b) (c)

Fig. 1. Cenosphere micrographs of (a) untreated (b) treated and (c) one such broken treated particle [49]. Wall thickness variations and built-in porosity in fly ash cenospheres are clearly evident from these micrographs.



(a) (b) (c) (d)

Fig. 2. Micrograph of as cast (a) E60-U (b) E60-T foams showing uniform dispersion of cenospheres. Lack of bonding for E60-U is seen in (c) while good interfacial bonding is evident from (d) due to silane treatment in E60-T.

evaluated. Five replicates of each volume fraction for both untreated and treated configurations are tested and average values are reported for analysis.

3. Results and discussions

3.1. Material processing

Syntactic foams prepared in the present work comprise of cenospheres both in as received (Fig. 1a) and silane modified (Fig. 1b) condition. Presence of numerous surface defects makes these fly ash cenospheres sphericity to deviate from perfectly spherical particle. Further, owing to very small coating thickness, silane layer is not visible from the micrograph as presented in Fig. 1b. Nevertheless, as presented in Ref. [49], surface modification of filler is confirmed through FTIR. In addition to surface defects, cenospheres are observed to have variation in wall thickness and more importantly porosity within the wall itself (Fig. 1c). Deviation of theoretically predicted values from experimental results might be due to these observations in these naturally available fly ash cenospheres. Particle size analysis of untreated and treated cenospheres is noted to be 76.3 and 98.1 μm respectively [49] having spericity range of 0.6–0.9 [48]. Experimentally computed densities of untreated and treated cenospheres are noted to be 920 and 1000 kg/m^3 respectively.

Syntactic foams are realised through manual stirring in the present work. Dispersing hollow fly ash cenospheres uniformly in epoxy matrix avoiding particle agglomerations is very crucial from mechanical behavior perspective. Further, particles survival from fragmenting during processing is a crucial parameter as broken particles adversely affect the mechanical properties. These fragments increase stress concentration and the density of the composites fabricated. Nevertheless, all of the above mentioned factors are dealt effectively with the manual stirring approach during fabrication, which minimizes particle failure to a great extent and facilitates uniform dispersion. Thereby, in the present work manual stirring is adopted for synthesizing cenosphere/epoxy foams. Fig. 2 presents micrography of as prepared cenospheres/epoxy foams. Low magnification micrographs of untreated (Fig. 2a) and treated (Fig. 2b) cenosphere reinforced epoxy foams exhibiting uniform dispersion confirm feasibility of adopted processing route. More importantly particle agglomeration is not observed for the foams with treated cenospheres as depicted by Fig. 2b. Higher magnification micrographs of E60-U (Fig. 2c) and E60-T (Fig. 2d) shows enhanced interfacial bonding between the constituents in surface modified filler foams as compared to their untreated counterparts. Improvement in overall mechanical properties in EXX-T foams is expected due to enhanced interfacial bonding leading to effective load transfer between the constituents. Failure mechanisms in foam composites are influenced by interface mechanism particularly for tensile and flexural loading scenarios as interfacial cracks in the form of debonding occur under such loading conditions [19,48,51,52]. On the other hand, bonding between the matrix and cenospheres does not affect compressive properties [53,54]. Non-uniform thickness of coating layer on cenospheres makes structure-property correlations very difficult [26] and thereby it's out of scope for the present study.

Experimental and theoretical densities are accounted for estimating void content in the prepared syntactic foam composites. Experimental densities are lower as compared to theoretical ones (Table 2) signifying entrapment of air during manual stirring route adopted. Though such entrapped air pockets compromise mechanical properties, very few voids are seen in the matrix as exhibited from Fig. 2a–b. Void content is seen to be increasing with filler loading except at E60 foam. Such an exception might be because of lower resin presence at higher cenosphere contents. Rise in mean particle diameter in treated cenospheres (98.1 against 76.3 μm as mentioned earlier) increases density of EXX-T as compared to EXX-U foams. Consistency in processing of untreated and treated cenospheres with epoxy matrix is clearly evident from narrow range of standard deviation values for experimental densities (Table 2). Weight saving potential of 5–14 and 4–12% is observed for EXX-U and EXX-T foams respectively. As these values for both foam types are varying in narrow range, specific properties needs to be looked into for proposing the better one in arctic environment.

Table 2
Density and Void volume fraction of syntactic foams [49].

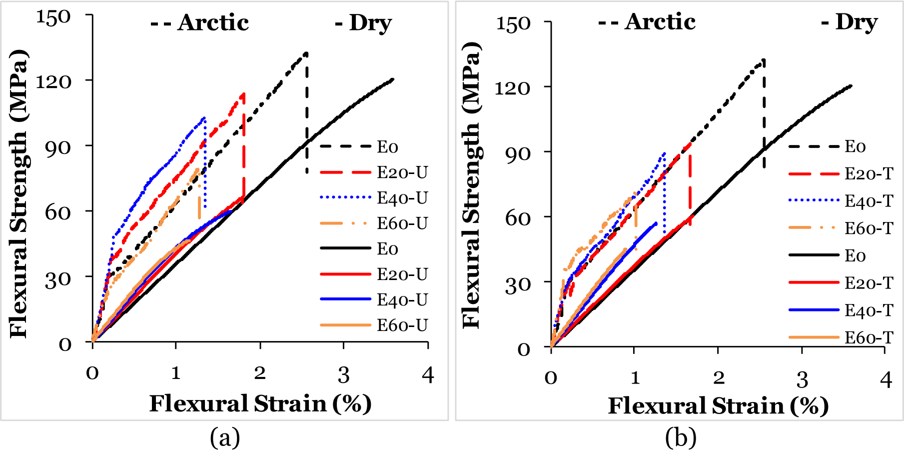
Material	ρ^{th} (kg/m^3)	ρ^{exp} (kg/m^3)	Φ_V (%)	Weight saving potential (%)
E	–	1192.00 ± 23.84	0.34	–
E20-U	1137.60	1129.63 ± 22.59	0.70	5.23
E40-U	1083.20	1064.72 ± 21.29	1.71	10.68
E60-U	1028.80	1028.36 ± 20.56	0.05	13.73
E20-T	1153.60	1133.14 ± 22.66	1.78	4.94
E40-T	1115.20	1073.92 ± 21.47	3.70	9.91
E60-T	1076.80	1055.65 ± 21.11	1.98	11.44

3.2. Flexural modulus and strength

Fig. 3 exhibits stress-strain response of representative samples. Irrespective of the testing environment, all types of syntactic foams fail in brittle mode post peak region. EXX-U foams exhibit non-linear behavior at room temperature as seen from Fig. 3a as compared to in Fig. 3b. Poor adhesion between the constituents (Fig. 2c) resulting in an unconstrained matrix flow around the cenosphere particles and relatively easier displacement of cenospheres within the matrix under applied load might be the reason for such an observation. Owing to enhanced interfacial bonding between the treated cenospheres and matrix, the response EXX-T foams are dictated by the cenospheres, resulting in a linear stress-strain response in the pre peak region as observed in Fig. 3b. In case of the arctic conditioned specimens, the stress-strain response curves presented two linear regions. The second linear region is used for all calculations to determine the stiffness and strength properties. Failure response is found to be similar in both the arctic conditioned and unconditioned samples, which resembles brittle fracture as mentioned earlier. Similar response under flexural mode at −60 °C is reported for carbon fiber reinforced composites [55].

Flexural modulus and strength values are computed for each case using the experimentally obtained load-displacement data. Fig. 4a–b displays the effect of filler loading and cenospheres treatment on modulus. With increasing filler content modulus for both foam types (EXX-U and EXX-T) increases (Table 3). EXX-T foams registered higher moduli at all the volume fractions as compared to EXX-U ones at room temperature. Further, all the foams out performed neat epoxy sample by registering higher flexure modulus (Fig. 4b). This trend is in-line with the results presented in Refs. [6,56,57]. In the case of the arctic conditioned samples also, untreated and treated cenospheres exhibit increase in modulus with increasing filler content. However, EXX-U foams register higher modulus values at all the volume fractions as compared to EXX-T foams. Neat resin registers lower elastic modulus as compared to EXX-U and EXX-T foams. Arctic conditioning increases the stiffness of the samples due to matrix hardening [58]. Further, for every 1 °C decrease in temperature, the modulus of the resin increases by 20 MPa [59,60]. In the present study, for every 1 °C decrease in temperature, an increase of 7.12, 5.94, 7.23, 3.72, 6.26, −1.34, −1.71 MPa is observed for E0, E20-U, E40-U, E60-U, E20-T, E40-T, E60-T respectively. Increase in modulus with decrease in temperature is found to be reasonable with the available literature, except for E40-T and E60-T foams. Hence, 11–14% weight saving in structures can be obtained by using cenosphere/epoxy syntactic foams (Table 2) with superior specific properties making these foams suitable for naval applications where structural design is driven by higher buoyancy criteria [61].

Flexural strength of cenosphere filled epoxy composites is exhibited

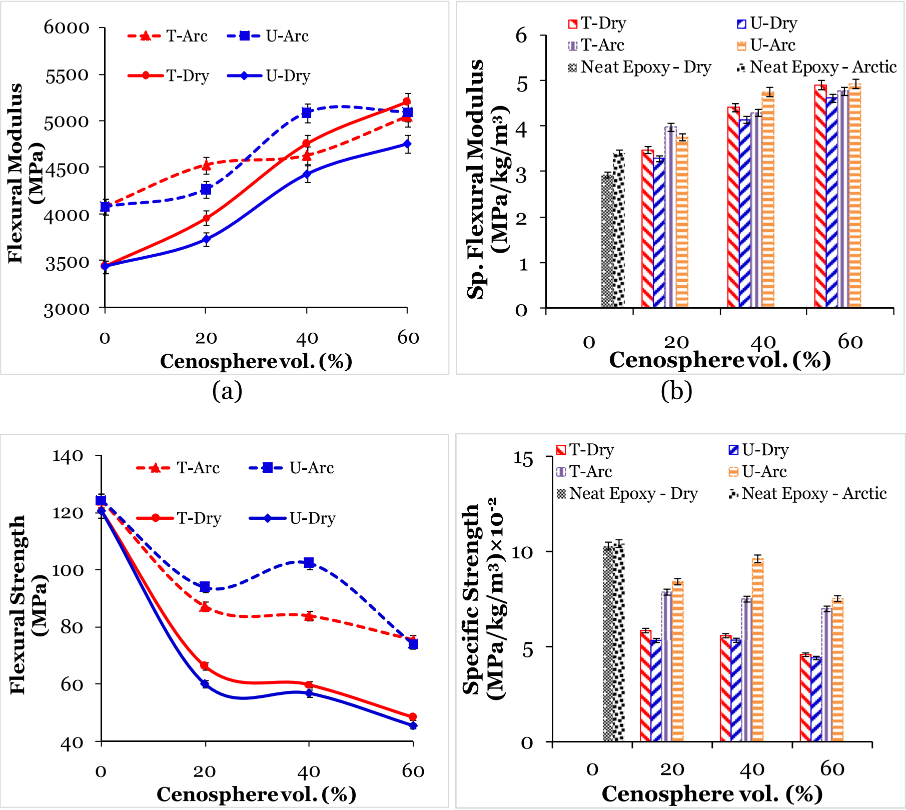


(a) (b)

Fig. 3. Representative flexural stress–strain curves of E20, E40 and E60 foams with (a) untreated and (b) treated cenospheres.

by Fig. 4c–d, where the flexural strengths for both EXX-U and EXX-T is lower as compared to neat resins load bearing capability at room temperature and arctic conditions. Specific strength (Fig. 4d) and fracture strain (Fig. 3) exhibit similar trend. However, foams with treated fillers have registered better response under room temperature test conditions whereas opposite trend is noted for arctic conditioned samples. Foam with untreated filler registered better response in arctic environment. As these foams can be used as core in sandwiches, lower fracture strength and strains do not limit their applicability in marine vessels. Filler content influences flexural strength significantly while marginal effect is noted due to particle surface treatment. Higher brittleness at the cenosphere-epoxy interface and silane modified particles might have played a significant role for such insensitivity pertaining to surface modification. Increasing filler content decreases strength implying reduction in foam strength owing to lower matrix content. Fracture features as presented in Fig. 5 indicate, matrix cracking post particle-resin debonding in EXX-U foams. Whereas, particles cracking (Fig. 5e) is the failure source for EXX-T foams.

Increase in flexural modulus of 7–15% for EXX-T foams is observed when arctic conditioned samples are compared to dry (unconditioned) samples. On the other hand, in case of treated samples it was observed that the modulus increased only for E20 samples by 14% while causing a reduction in its modulus by 3% as the filler content increased. In case of flexural strength, an increase between 56-80% and 31–56% was observed for EXX-U and EXX-T respectively in in-situ arctic samples. Arctic conditioned samples became more rigid causing increase in flexural modulus and strength. For arctic conditioned samples, increase in flexural strength of neat epoxy samples is less as compared to EXX-U



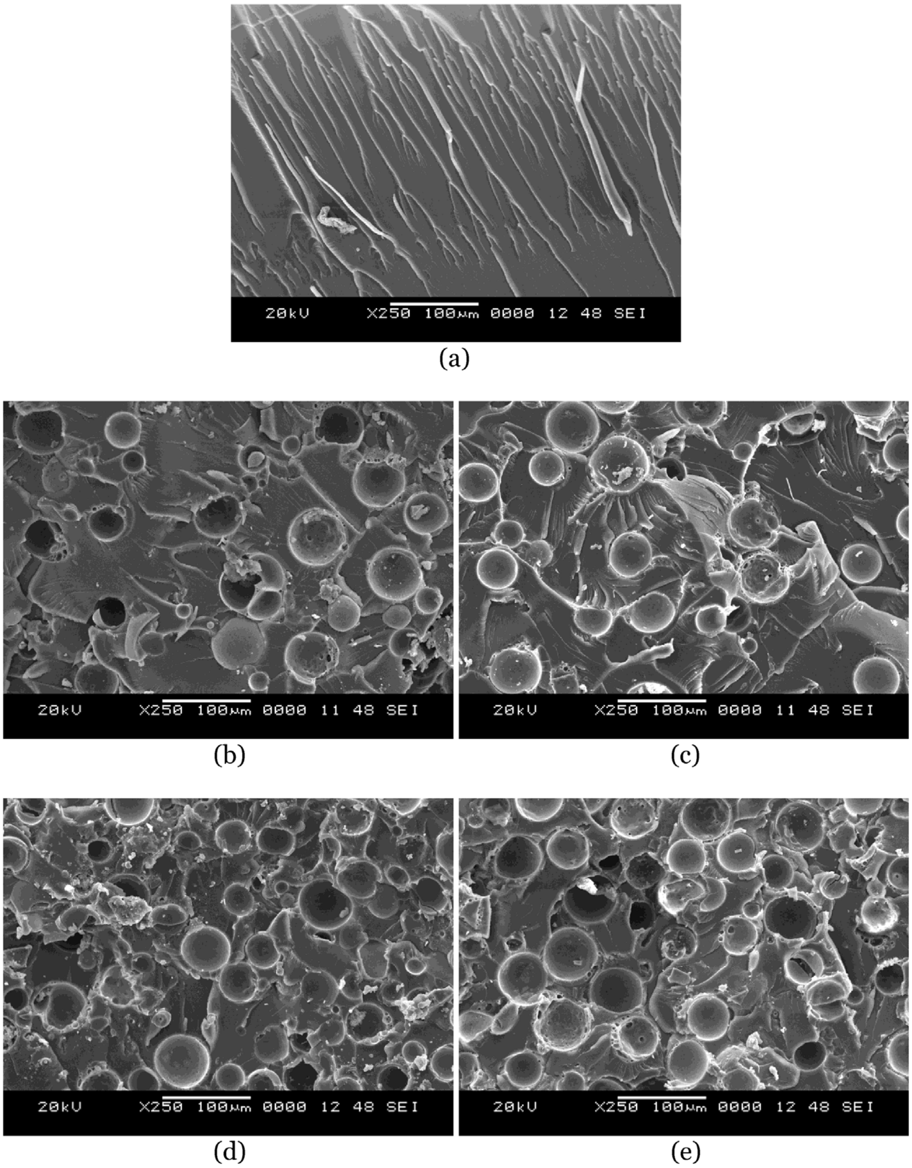
(a) (b)

(c) (d)

Fig. 4. Experimentally measured flexural (a) modulus (b) specific modulus (c) strength and (d) specific strength of prepared samples.

Table 3
Modulus and Strength properties of syntactic foams.

Material	Flexure (MPa)			
	30 °C		−60 °C	
	Modulus	Strength	Modulus	Strength
E	3436.98 ± 68.74	120.29 ± 2.41	4078.49 ± 101.96	124.12 ± 3.72
E20-U	3729.55 ± 74.59	60.09 ± 1.20	4264.80 ± 85.30	93.81 ± 2.35
E40-U	4431.51 ± 88.63	56.74 ± 1.13	5082.54 ± 152.48	102.26 ± 3.07
E60-U	4755.30 ± 95.11	45.23 ± 0.90	5090.78 ± 178.18	73.88 ± 2.59
E20-T	3958.71 ± 79.17	66.23 ± 1.32	4522.59 ± 90.45	87.02 ± 2.18
E40-T	4746.83 ± 94.94	59.82 ± 1.19	4625.50 ± 138.76	83.77 ± 2.51
E60-T	5196.11 ± 103.92	48.28 ± 0.97	5041.52 ± 176.45	75.50 ± 2.64



(a)
(b) (c)
(d) (e)

Fig. 5. Micrographs of (a) Neat epoxy resin (b) E20-U (c) E20-T (d) E60-U and (e) E60-T post flexure room temperature tests.

and EXX-T foams. Due to arctic conditioning, the matrix shrinks around the cenosphere particles inducing residual tensile stresses in the matrix and compressive stresses on the cenosphere particles. Neat epoxy exhibits slight increase in strength as compared to room conditioned sample owing to hardening of matrix. Further, arctic conditioned EXX-U and EXX-T foams exhibit higher strength compared to room conditioned samples owing to better interlocking of the cenosphere particles with matrix resin.

For the case of arctic conditioned samples, the degradation caused by the environmental exposure can be observed to be more predominant in E40 foams. A combined effect between the matrix and the cenospheres exists in the mechanical properties of the samples. Given that the interphase between matrix and cenospheres has a higher influence on the material properties for this configuration, a higher degradation of this region may lead to a decrease in its properties. Treated cenospheres samples have better adhesion between matrix and cenospheres. Exposure to temperatures of −60 °C results in higher degradation of the interphase as compared to untreated samples leading to a higher difference as observed in Fig. 4a and c. On the other hand, 20 and 60 vol % are matrix and cenospheres dominated respectively and the interphase influence is not significant at these two filler loadings.

The fracture features of E0, E20 and E60 untreated and treated cenosphere reinforced foams at room temperature tests are presented in Fig. 5. The micrographs are taken post flexure test on the fractured surfaces. Absence of debris is observed in all these micrographs indicating tensile fracture [26]. Such a feature is also noted in syntactic foams with cenospheres in thermoplastic (HDPE) matrix [19,48] like in thermosetting (epoxy) ones. In flexural loading conditions, debris absence on the fracture surface is due to crack initiation from the tensile side of the sample which governs the brittle mode of fracture. Extensive plastic deformation marks are seen on neat epoxy samples without any debris as observed in Fig. 5a. Interaction of the deformation waves as seen in Fig. 5a with untreated and treated cenospheres are worthy of investigation. Fig. 5b and d shows debonding and displacements of cenospheres from the matrix (EXX-U) during the deformation and fracture as compared to EXX-T (Fig. 5c and e). This implies that most of the stress in the composite is withstood by the matrix material in foams with treated filler that determines the composite failure strength. This is obvious owing to good interfacial bonding between the constituents in EXX-T (Fig. 2d) foams. Strength values of foams with treated particles are higher compared to untreated ones for all the compositions tested at room temperature. Constrained matrix movement around relatively tougher treated particles registered higher strength values. With increasing filler content variations in particle sphericity, wall thickness and built-in porosities (Fig. 1c) induce additional stress concentration suppressing silane coating effect and thereby lowers flexure strength. Though these foams have limitations in strength, they are promising in terms of high stiffness if used in sandwich composites as core materials.

Fracture features for representative syntactic foam containing 40 vol % of untreated and treated cenospheres in arctic environment can be observed in Fig. 6 and Fig. 7 respectively. All micrographs are obtained across the fracture surfaces post flexural tests. Similar fracture features are observed for both treated and untreated samples. Like for unexposed samples, tensile fracture is also observed in arctic conditioned samples.

4. Conclusions

Room and arctic temperature effect on EXX-U and EXX-T cenosphere/epoxy foams under flexure is presented in this work. Specific modulus in flexure is observed to be considerably higher than the neat epoxy resin. Flexural modulus of these foams can be effectively tailored by filler surface modification and varying filler volume fraction. Resin content governs the strength of these lightweight foams. It is observed that the flexural strength decreases as the filler content increases. Lack of interfacial bonding between the foam constituents limits the load transfer at the interface for composites with untreated cenospheres. Similar trend is observed for treated particle foams owing to geometrical imperfection with such naturally available fillers. Arctic environment is simulated by subjecting the foams to −60 °C. Lower failure strains in EXX-U and EXX-T foams compared to E0 is also noted. Arctic exposed samples reported a slight increase in their modulus of elasticity as compared to room temperature samples.

Key finding were as follows:

1. Weight saving potential for EXX-U and EXX-T foams is 11–14% as compared to neat resin samples.
2. An increase in flexural modulus was observed in syntactic foams at room and arctic temperature as compared to neat resin at room temperatures, whereas flexural strength is noted to be decreased.
3. An increase in flexural modulus between 7-15% was recorded for syntactic foams with untreated cenospheres under arctic conditions as compared to the ones tested at room temperature.
4. EXX-U and EXX-T foams exhibit higher specific modulus as compared to E0 samples for room temperature and arctic conditioned samples. Specific strength of arctic conditioned EXX-U and EXX-T foams is significantly higher compared to room conditioned samples.

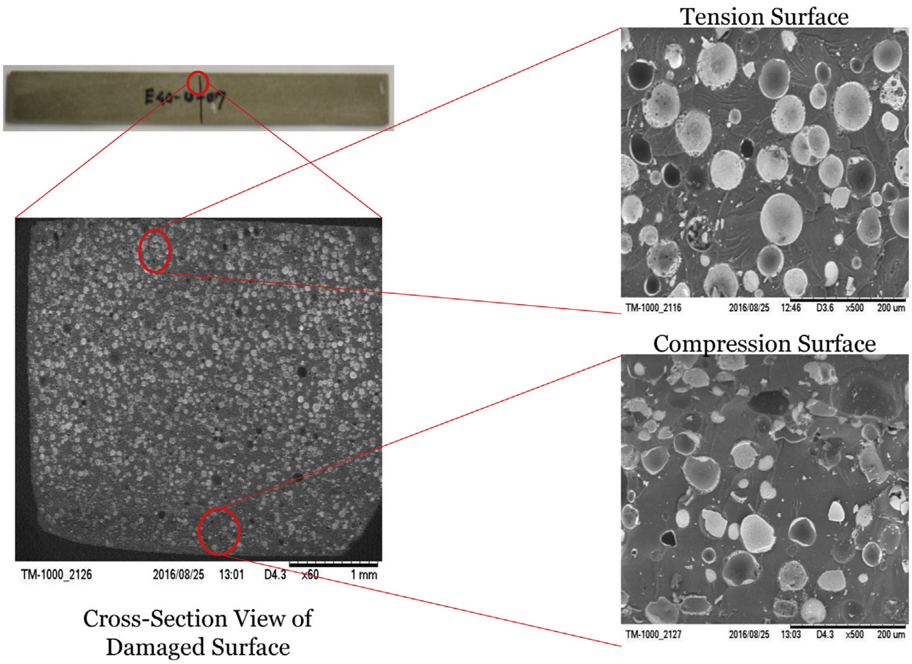


Fig. 6. E40-U Flexural Specimen Schematic post arctic condition test.

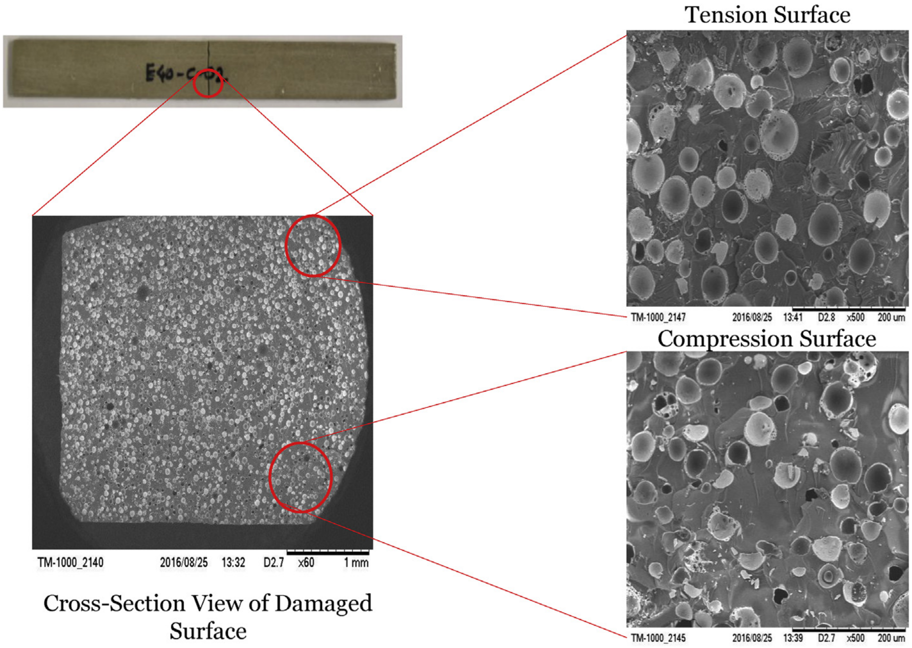


Fig. 7. E40-T Flexural Specimen Schematic post arctic condition test.

Flexural strengths of arctic exposed EXX-U and EXX-T syntactic foams increased in the range of 56–80 and 31–56% respectively as compared to those at room temperature. This is accredited to matrix hardening experienced by the samples when exposed to arctic temperatures that facilitates the cenospheres to carry more load. After examining the behavior of syntactic foams in arctic environment, it is concluded that the flexural modulus increases with arctic exposure and filler volume percentage. These materials systems have great potential to be used as core materials for sandwich construction in such extreme conditions, where a significant improvement in the flexural modulus can be achieved with better weight saving potential and specific values. However, due to inferior flexural strengths, using only syntactic foams in primary load bearing structures without other high strength materials, like carbon or glass facings, is not suggested. The findings reported here offers a pathway to improve the structural integral design by taking advantage of the favorable results in terms of low density and better modulus of elasticity and avoiding the unfavorable ones.

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