American Journal of Materials Science 2017, 7(4): 83-90
DOI: 10.5923/j.materials.20170704.03

A Review on E-Glass/ Epoxy Composite Combined with Various Filler Materials and Its Mechanical Behaviour under Different Thermal Conditions

Abhijith Vaidya S.[1,*], T. Rangaswamy[2]

[1]Department of Mechanical Engg, Adichunchanagiri Institute of Technology, Chikmagalur, India
[2]Department of Mechanical Engg, Government Engg College, Hassan, India

Abstract The present study is an attempt to take an overview of the work done in the area of E-glass/ Epoxy composite materials with various filler materials. E-glass/Epoxy composite is chosen based on its applications and ease of manufacturing techniques. The reinforcement of various glass fibres, additives with epoxy resin has been observed. Also, this review paper focuses on selection of suitable filler material among Al_2O_3, SiC, B_4C, $Mg(OH)_2$ and various chemical additives for E-glass/Epoxy composite. The review mainly narrates the behaviour of said composites under various temperature conditions. Cryogenic treatment has been done by various researchers for the applications of E-glass/Epoxy composite in Liquefied natural gas (LNG) carriers. This work proposes a polymer matrix composite with suitable filler material and that may be treated at cryogenic temperature for exploring its mechanical behaviour.

Keywords E Glass/Epoxy, Filler material, Hardener, Cryogenic temperature

1. Introduction

Composite materials application has been a trend due to its load sustaining capacity in various engineering applications under different atmospheric conditions. Polymer matrix composite is one of the major composite type having wide applications. E-glass/epoxy is one of the versatile types of composite based on its flexible production technique. Recently composite material manufacturing is not constrained to using a matrix and reinforcement but also combined with various filler materials like Al_2O_3, SiO_2, TiO_2, B_4C [1-3], graphite [11-14], ZnO_2, CaO_2, MgO, $Mg(OH)_2$ [15-18], ceramic whisker like potassium titanate [4], and chemical additives like polyurethane, polymeric foams [34-38] etc. The reason is to enhance the mechanical characteristics of E-glass/epoxy composite.

This article summarizes various fillers, additives, ceramic whiskers used in fabrication of E-glass/epoxy composite and its mechanical behaviour before and after the implementation of said materials. Another view point of this article is to observe the mechanical behaviour of the composite when it is used for applications at cryogenic temperature. One among such application is to carry the LNG in Cryogenic Containment System (CCS). The primary barrier layer in CCS is made from steel. Research works are conducting to install a composite material for primary barrier layer in CCS. An attempt is made from this review study that how E-glass/epoxy composite is modified with fillers, additives and also its behaviour under cryogenic conditions.

* Corresponding author:
abhi1vaidya@gmail.com (Abhijith Vaidya S.)
Published online at http://journal.sapub.org/materials

2. Literature Review

Metin Sayer [1] evaluated the elastic properties and calculated buckling load for E-glass/epoxy composites added with ceramic fillers. Specimen plates made of composites with 0% (unfilled), 5%, 10% and 15% particle weight fractions of silicon carbide and two particle sizes of aluminium oxide and boron carbide are considered. The fabrication used ceramic particles added to epoxy resin in order to decrease the viscosity of resins. Mixing ratio of resin to hardener in weight is 100: 45. The mixtures are mixed thoroughly for 30 minutes using a mixer, with proportional weight percentage. It is observed that the addition of 10% weight of boron carbide particles to composite increases almost 42% of buckling load as compared to other ceramic fillers. The density and particle size of Al_2O_3 3.65g/cm^3 and 4 µm which is greater than the other fillers.

Ramesh K Nayak et.al [2] modified the epoxy matrix by Al_2O_3, SiO_2 and TiO_2 and explains the significant improvement on mechanical properties with epoxy matrix modification. Al_2O_3 < 200 micron, SiO_2 < 10 micron and TiO_2 < 300 micron are selected. E glass fibre of 8 micron thickness as reinforcement and epoxy resin biphenyl-A-diglycidyl-ether belongs to epoxide are considered. It is observed that mechanical properties such as flexural strength, modulus, ILSS are more in SiO_2 modified epoxy due to smaller size particle. Al_2O_3 modified composite increases the hardness and impact energy.

P.K. Palani et.al [3] focussed on analysis of nanoclay content affected on mechanical behaviour of chopped strand mat E-glass fibre reinforced in epoxy matrix. The specimens are fabricated with 1%, 5% and 7% weight nanoclay with 30% weight fibre, epoxy resin and hardener. 10: 1 is the weight ratio of resin to hardener. It is observed that tensile, flexural strength and hardness of 5% weight nano clay are larger compared to 1% and 7% weight. This work suggests the fabrication compatibility of E-glass/epoxy with nanoclay.

M. Sudheer et.al [4] developed E-Glass/epoxy composite with ceramic whisker and solid lubricant as fillers are fabricated using vacuum bagging technique. The matrix system is a medium viscosity epoxy resin and amino based hardener, reinforced with plain woven fabric type E-glass fibre having filament diameter 9 µm. Potassium titanate whisker [PTW] with diameter of 0.2 to 2.5 µm and length 10 to 100 µm, graphite as lubricant filler of size less than 50 µm are added. Mechanical properties like tensile, flexural and impact properties are evaluated as per ASTM standards. Also, wear tests conducted for dry sliding condition. Composites with 2.5% weight of graphite as filler have improved its mechanical property, whereas addition of PTW alone has reduced. Dry sliding performance of the composites particularly PTW alone increased coefficient of friction, whereas with graphite, it has reduced.

S. Basvarajappa et.al [5] done on E-glass/epoxy composite using silicon carbide and graphite particles for finding out the dry sliding wear characteristics. The matrix materials used is a medium viscosity resin cured with polyamine hardener. SiC and graphite is selected as filler materials based on the ability to sustain high temperature and to lower the thermal expansion. After dry sliding wear test, it is observed that addition of fillers to the composite leads to better wear resistance. Higher the percentage of SiC with graphite leads to high wear resistance due to abrasive wear performance of parent material.

M. Alagar et.al [6] compared two types of reinforcement combined with siliconized epoxy composite and studied thermal characteristics. E-glass and Kevlar 49 are two reinforcements selected for the epoxy resin prepared by hand layup technique. The materials used are 10 mil bidirectional E-glass fibres, heated around 150°C in hot air oven and cooled to 30°C. E-glass reinforcement with epoxy resin shows better adhesion than Kevlar 49 due to the presence of ionic states.

J. Chen et.al [7] used polysiloxane - based core shell rubber particles for the modification of epoxy resin with different additives. Epoxy resin is added with diglycidyl ether of bispenol - A [DGEBA] and polysiloxane core shell rubber [S-CSR] an araldite group. Rubber particles processed to crosslink of polysiloxane core at glass transition temperature of -100°C up to 20% weight of S-CSR particles and mean diameter of 0.18 µm is used. Mechanical properties at cryogenic range temperature are evaluated. It is concluded that addition of S-CSR particles increased fracture energy up to 947 J/m^2 at 20% weight. Further, addition increases toughness at cryogenic temperature but the fracture energy decreases below room temperature. Compressive stress increases rapidly between -80°C and -109°C which increases linearly from 20°C to -80°C.

Epoxy composite reinforced by chopped glass fibre and added with different weight % of SiC filler. Experiments were conducted by Gaurav Agarwal et.al [8] for tensile, hardness, flexural, ILSS properties, physical and thermal properties. The mechanical properties mentioned increases with the addition of SiC by 10-15% weight beyond 15% decreases. Thermal properties are evaluated at 20°-90°C resulting, the composite changes to rubber state and therefore stiffness and mechanical properties were reduced.

Glass reinforced epoxy composite processed by autoclave process has been experimented to retrieve mechanical behaviour at different temperature and loading speeds. Sangamira Sethi et.al [9] concluded that ILSS decreases during temperature above normal level because of thermal conditioning effect leads to spreading of process zone in matrix resin and impart fibre detaching. Laminates are produced for unidirectional, cross ply, quasi-isotropic ways and temperature dependent parameters such as tensile strength, young's modulus were found. H. Mivehchi et.al [30] identified that fatigue damage is increased with increasing temperature.

Three different particulate fillers are added to epoxy to identify the behaviour of tribological properties. K. Srinivas et.al [10] selected graphite, SiC and graphite-SiC of 10mm diameter and 25mm length conducted wear testing on computerised pin disc apparatus. Combined effect of graphite-SiC gives more wear resistance particularly at 5% graphite and 35% SiC rather than individual supporting for wear resistance.

Bankim Chandra et.al [11] reviewed the mechanical properties of FRP composites at varying loading speeds. The article focussed on investigation and overview of tensile and compression behaviour and in plane shear behaviour of specimens at different strain rates. For the above parameters described, an overview of glass, carbon and Kevlar fibres have made and their instability on environmental conditions has drawn. It has been observed that to sustain the structural stability and system integrity, fibre or polymer interfaced in composite material play a vital role; and hence under loading, its function is critical and conclusive in stress transmissibility.

Thermal and mechanical properties of epoxy/SiC composites are investigated by Juana Abenojar et.al [12] exposing them to moisture. Resin DGEBA (Epofer) and hardener Epofer 432 in the ratio of 100/32 by weight % used at the room temperature (RT) 25°C and 30°C, and relative humidity (RH) 30% during 24 hrs. The effect of temperature and moisture are evaluated on specimens, by treating them to varying aging conditions 60°C & 5% RH; RT & 95% RH; 60°C & 95% RH. And kept for 30 days in this condition and thereafter stabilised for another 24hrs in a desiccator. The absorption of water causes the plasticization in the material and thus reduces the Glass Transition temperature (T_g) and resistance. The brittleness and cross linking in material produced due to desorption of water increases the strength and T_g.

The abrasive wear behaviour of granite filled glass epoxy composites with SiC was done by S Basavarajappa et.al [13] using structural analysis. The addition of granite in glass epoxy composites as secondary reinforcement increases abrasive wear resistance was investigated in this article. M G Bhagyashekar et.al [14] studied the effect of wear behaviour of particulate filled SiC epoxy & graphite-epoxy composites using pin-on-disc arrangement. The addition of fillers with epoxy composites gives increased wear resistance of composites particularly with graphite epoxy.

Dinesh Kumar et.al [15] investigated the mechanical performance of carbon nanotube (CNT) filled E-glass/epoxy composite at elevated temperature. Weight fraction of E-glass and epoxy was 60:40. The hardener used was Diglycidyl Ether of Bisphenol-A. CNT with 0.1%, 0.3% and 0.5% of weight with respect to weight of epoxy resin is chosen. It is observed that flexural strength is increased by 32.8% for 0.1% and also mechanical properties degradation at elevated temperature of 110°C is more in 0.1% compared to other compositions.

A review on preparation and various types of glass fibre reinforced polymer done by T. P. Satishkumar et.al. [16]. Different methods of preparation of GFRP matrix, their mechanical, environmental properties and applications are discussed. Optimum weight % of chemical composition like Al_2O_3, SiO_2, TiO_2, B_2O_3, CaO_2, MgO, Na_2O, K_2O and Fe_2O_3 for C, S, A, D, R and E glass type of fibres are reviewed.

For the thermal management used for heat transfer application, different polymer composites with heat sink materials are used. Its behaviour related to thermal and mechanical aspects reviewed by M.A. Vadivelu et.al. [17]. Heat sink materials for various polymers and its density, thermal conductivity, processing temperature etc. are reviewed. Copper, silver, aluminium, nickel, iron etc. along with LDPE, HDPE, polystyrene etc. are studied. Overall thermal conductivity and selected parameters carbon, graphite, CNTs and carbon fibres gives better performance and thin polymer structure for thermal sink equipment will be better design option has been concluded.

K. Devendra et.al [18] selected E-glass reinforced with epoxy composites using Al_2O_3, $Mg(OH)_2$, SiC and haematite powder as filling materials, tested the properties of thermal conductivity, thermal expansion coefficient, ignition time and rate of flame propagation of composites. The composites are fabricated by hand layup technique with the variation in the % of glass fibre, epoxy and filler materials by volume. The results concluded that 10% volume of Al_2O_3 and Mg $(OH)_2$ give low thermal conductivities but 10% SiC have more thermal conductivity.

Experimentation has been done using hexagonal boron nitride reinforced epoxy composites by Wenying Zhou et.al [19] to examine thermal, electrical and mechanical properties. Polymer used was diglycidyl ether of bisphenol A, flexible epoxy resin TA30 and methyl hexa hydropthalic anhydride as curing agent. Thermal properties like T_g has increased, before filler loading levels reached 40% weight, after 40% weight it began to decrease.

V C Beber et.al [20] investigated the effect of temperature on the fatigue behaviour of toughened epoxy adhesive which is used for structural applications. The epoxy adhesives as bonded joints which are subjected to cyclic loading were investigated corresponding to fatigue and also influence of temperature on fatigue life. Dynamic mechanical analysis conducted taking stress ratio, frequency and five range of temperature. After the analysis, there will be decrease in fatigue life with increase in temperature.

Dalila Laouchedi et.al [21] investigated the property of epoxy resin with two sets of clay particles i.e., Kaolin and calicined kaolin with different particle sizes. These clay fillers are untreated kaolin initially and kaolin which is calicinated at 500 - 550°C for 5 hours which are considered as binders. With four different particle sizes and volume fractions, <1µm, 4 µm, 30 µm and 200 µm with 20%, 40%, 20%, 15% are taken and samples are made. Modulus of elasticity has been increased around 325%. Glass transition temperature increased but overall the clay fillers are not fit for epoxy until it is chemically treated.

Glass fibre epoxy composite with Al_2O_3-SiC of different proportions are made for mechanical behaviour analysis done by S. Rajesh et.al [22]. Silica glass, resin hardener HY951, polyester resin, Al_2O_3 and SiC were taken and casted. Shear strength, biaxial, tensile strength was increased with addition of filler materials.

A study on durability performance of polyester, vinyl ester and epoxy glass FRP bars used for concrete structure was conducted by Brahim Benmokrane et.al [23]. Tests have been conducted for mechanical properties with unconditional GFRP and all the mentioned resins are tested with GFRP blended with alkaline solution for measuring durability. Epoxy and vinyl ester GFRP showed higher fibre resin bond, flexural modulus of elasticity and ILSS. There will be small reduction in flexural strength after immersion in alkaline solution for 500 hours for polyester and epoxy GFRP. Vinyl ester has more reduction value.

L M Soffer et.al [24] evaluated mechanical properties of epoxy resins at cryogenic temperature, with four modified resin systems kept at 75°, -320° and -423° F. Epoxy 828 - Empol 1040, Epoxy- Bohet, Epoxy - Adiprene, and Epoxy 826 - Empol 1040 are four types of resins considered for experiment. Epoxy 820 - Empol 1040 and Epoxy - adiprene resin combination gave the best mechanical properties out of four combinations, in particular, epoxy with adiprene combination. The mechanical properties include tensile, impact, notch toughness and ILSS were tested.

The function of multiwalled carbon nanotube (MWNT) on mechanical properties combined with epoxy composite at cryogenic temperature is investigated by Yuxin He et.al [25]. MWNT are treated with maleic anhydride, isophorone diisocyanate and grafting is done. The grafted MWNT reinforced with epoxy gives higher cryogenic properties at 77K that to in room temperature with neat epoxy.

A study on filament resin materials made of glass, boron, graphite with epoxy in cryogenic application is investigated for various mechanical properties by Morgan.P. Hanson [26]. Cryogenic tensile strength, shear strength characteristics determined at 297, 77 and 20K respectively. Cycle tests are done on cylindrical specimen's having aluminium foil liners at 77 and 20K to find cycle life and mode of linear failure. At these temperature range glass, boron, graphite composite showed increased ILSS, filament effectiveness, reduced strain and significant increase in tensile strength.

Hai-lam Ma et.al [27] evaluated impact properties of E-glass/epoxy composites at cryogenic environment. Woven E-glass, Araldite epoxy GY251 and Aradur HY956 hardener in ratio of 5:1 mixed thoroughly. Samples were prepared and exposed to temperature scale of 295K (room), 199K (dry ice) and 100K (cryogenic) for conducting low velocity impact tests. Post curing of samples with epoxy leads to increase in energy absorption at any temperature.

M. Surendra Kumar [28] et.al carried out mechanical behaviour testing by selecting e-glass fibres with epoxy resin at cryogenic temperature. Chopped E-glass fibres treated with silane sizing, araldite epoxy and hardener HY-951 fabricated using wet layup, rolled and after desired thickness obtained. The layer structure allowed to hard for 48 hours. Laminates are prepared and exposed to temperature of 77K. Three point bend test and flexural tests were performed at 2, 50, 100, 200 and 500m/min crosshead speed. ILSS of chopped fibre is less than woven fibres. After cryogenic treatment, ILSS enhanced to higher value due to epoxy concentration at low temperature.

E-glass/epoxy composites subjected to low temperature are tested for tensile, compression and shear properties under mechanical load by Mohammed A Torabizadeh [29]. The temperature range of 25°C, -20°C and -60°C were applied and results indicated that strength and modulus of unidirectional composites have significant effect on low temperature. At -60°C, 12% strength increased and failure of material decreased by 10%.

Guo Zhi Ma et.al [31] selected a problem having copper based metallic glass matrix, implemented cryogenic treatment for studying microstructure and mechanical behaviour. In liquid nitrogen, the samples are dipped for 4, 24, 60 and 72 hour time duration as cryogenic treatment. The hardness and compressive fracture strength have been improved from 512 HV to 574 HV and 1340 MPa to 1759 MPa respectively.

Table 1. Comparison Table of Composite testing at room Temperature

Type of Fibre/ Resin	Additives/ Filler materials	Hardener	Volume fraction/ Temperature	Properties Evaluated	Result	Ref
E-Glass/ Epoxy	SiC, Al_2O_3, B_4C	-	5,10,15% SiC, Al_2O_3, B_4C	Elastic and Buckling load	Properties increased by addition of fillers	1
E-Glass/ Epoxy	Al_2O_3, SiO_2, TiO_2	DGEBA	10% weight of fillers	Flexural strength, ILSS	Properties exhibit more in SiO_2	2
Chopped mat strand E-Glass/ Epoxy	Nanoclay	Araldite LY556	1,5,7,30% wt fibre: epoxy	Tensile, flexural, hardness	5% nanoclay have greater result	3
E- Glass/ epoxy	SiC, Graphite	Polyamine	-	Wear	Increases by addition of fillers	5
Epoxy	-	DGEBA & CSR	20% weight CSR, Temp -100°C	Fracture	Increases	7
Chopped E-Glass/ epoxy	SiC	-	10-15% SiC; 20-90°C	Tensile, hardness, flexural, ILSS & thermal	SiC not functional at high temperature	8
Epoxy	SiC	DGEBA, Epofer 432	25-30°C; 30% Humidity	Thermal and mechanical	Thermal conductivity increases w.r.to time & temp of Nano composites.	12
E-Glass/epoxy	Granite	Polyamine	40% Epoxy, 20% of granite, 40% Fibre	Wear	Increases abrasive wear	13
E-Glass/epoxy	Al_2O_3, SiC, $Mg(OH)_2$, Haematite	-	10% of $Mg(OH)_2$ Al_2O_3	Thermal behaviour	Composite with Haematite have high thermal conductivity	18

The cryogenic temperature range of -150°C applied for glass fibre with adhesive bonded metal joints for liquefied natural gas (LNG) containment applications. Chang Seon Bang et.al [32] observed that lap shear strengths of adhesive joints made of aluminium and stainless steel decreases at cryogenic temperature. Tomo Takeda et.al [33] made one using woven glass / epoxy modified with n – butyl glycidyl ether and multiwalled carbon nanotube. Tensile tests were conducted in cryogenic temperature (77K*)* and properties evaluated. Only fatigue life increased by addition of modifiers and young's modulus, ultimate strength merely changed. The research demonstrates the capability to improve the matrix dominated properties of composite materials at cryogenic temperature by adding carbon nanotube and soft modifiers.

Ilbeom Chi et.al [34] developed an insulation board composed of E-glass/epoxy with polymeric foams to seal a foam blowing gas of low thermal conductivities at LNG carries. The thermal insulation performance is optimal at a density 30-50 kg/m^3 with almost equivalent mechanical performance, effective thermal conductivity of thermal insulation board was 0.018 W/m°K, 31% lower than the conventional. The earlier work has taken as reference and evaluated the cryogenic characteristics of chopped glass fibre reinforced with polyurethane foams [35]. At room temperature of 25°C and cryogenic temperature of -150°C, compression, tension and fracture toughness tests were evaluated. It is found that compressive strength increased from 35% to 54% at room and cryogenic, tensile 220% to 210%, fracture toughness 250% to 360% respectively with 10% weight reinforcement of chopped fibre with polyurethane foam.

At cryogenic temperature Tomo Takeda et.al [36] investigated tensile behaviour of woven glass/ epoxy composite laminate. By FEM analysis, it is found that uniaxial and uniform stress field is obtained in the specimen with large gage section thickness and large crossing beam thickness fails in desirable mode.

Hei Cau Me et.al [37] experimented to identify impact properties of glass fiber epoxy at cryogenic temperature and exhibited that they have smaller damage and were stiffer at that condition; however energy absorbing ability is poor. Temperature range of 235K room, 199K dry ice and 100K cryogenic conditions are taken into account and 18 GFRP samples made to ASTM standards. Low velocity impact tests conducted with post curing condition, reduces damage depth, stiffness and increases elasticity of materials. Composites absorb less energy at low temperature due to interfacial bonding between fibre and matrix.

Fracture toughness of polyurethane adhesive joints with glass fibres improved at cryogenic temperature by Sooyun Nam et.al [38]. They evaluated reliability of polyurethane adhesive at -150°C and measured fracture toughness with respect to length and volume fraction of chopped glass fibres. Regarding its application in LNG carrier, two types of metal sheets aluminium and stainless steel are bonded with polyurethane adhesive. It is identified optimum volume fraction is 20% and chopped glass fibres of 3mm length for polyurethane adhesive for aluminium and stainless steel joints at cryogenic temperature among 25%, 20% and 15% fractions with respect to fracture sustainability.

Zhi Xiong Wu et.al [39] investigated the effect of matrix modification on ILSS of glass FRP at cryogenic temperature. Resins used were diglycidyl ether of bisphenol F, curing agent diethyl toluene diamine, other resins used were liquid aromatic hyper branched epoxy resin, isoproplidene bisphenol for modifying matrix. By keeping the fiber layer in metal mould at 120°C for 10 hours heat treated, then resins and 10% weight were mixed at 45°C using mechanical stirring. ILSS of GFRP is lesser compared to addition of additives to glass fibres at 77K.

Table 2. Comparison Table of Composite testing at Cryogenic Temperature

Type of Fibre/ Resin	Additives/ Filler materials	Hardener	Temperature/Time duration	Properties Evaluated	Result	Ref.
Woven E-glass /epoxy		Araldite GY251 Aradur HY956	295K, 199K and 100K	Low velocity impact test	Stiffness increased and depth of damage is small	27
Woven glass / epoxy	N butyl glycidyl ether	Multiwalled carbon nanotube (CNT)	77K	Fatigue	Increased due to CNT	33
E-Glass/ epoxy	Polyurethane foams	-	25°C and -150°C	Compressive and fracture	Both increases by 54% & 360% at -150°C	35
Woven glass / epoxy	-	-	77K	Tensile	Uniform stress obtained at large gage	37
Chopped E-Glass/epoxy	Polyurethane adhesive	-	-150°C and 15,20,25% fibres	Optimum Volume fraction of fibre	20% is suitable at -150°C for LNG carriers	38
Kevlar fibre	Acetone fluid	-	77K for 12 hours	Fibre strength IFSS Abrasion resistance	Increased up to 50%	43

In cryogenic containment system (CCS) of LNG carrier, the primary barrier will be -163°C under 0.11 MPa. Dongyoung Lee et.al [40] investigated that the primary barrier buckles by cavitations impact of LNG and produces crumbling noise. They proposed corrugation of primary barrier reinforced with E-glass/epoxy to increase bucking capability and to reduce noise issues. At -163°C, glass fibre, and polyester and polyethylene fabric damaged a bit by impact and retained damping resistance. Hence glass fibre epoxy with polyethylene fabric may reduce vibration and impact load transmission.

In CCS for LNG carrier, the primary barrier is of stainless steel, and secondary barrier is made of glass fabric composite, sealed using an adhesive. Bu Gi Kim et.al [41] experimented on a new way of measuring gas leakage through this adhesive and thermal residual stress of joint. Two face glass fibres and inner Al foil was investigated with respect to curing cycle exposed to temperature of 60°C, pressure of 10 KPa for 10 hours which decreased 53% of gas leakage, compared to any other curing cycles.

The adherences of stainless steel and Al sheet in CCS for LNG ships were studied by Chang Seon Bang et.al [42]. An optimum reinforcing volume fraction of glass fibre was found at 15% fibre volume fraction, lap shear strength increase to 3.4 times, fracture toughness 55.5-60% increased. The thickness will be 0.5mm-10mm as optimum for adhesive bonds.

Kevlar fibres were treated to different cooling rates at cryogenic temperature then Interfacial Shear strength (IFSS), tensile and wear properties were investigated by Fujan Xu et.al [43]. Kevlar fibre strength is increased by 24.9%, IFSS slightly changed. Further abrasion resistance of cryogenic treated fibres increased above 50%.

3. Conclusions

This review of E-glass/epoxy composites combined with various reinforcements, modified with different filler materials are studied with respect to their mechanical, physical properties. Also, the review describes how the E-glass/epoxy composites behave at various temperatures, mainly in cryogenic range. Major conclusion can be drawn from the study are:

i. E-glass/epoxy composites combined with Al_2O_3, SiC, B_4C, Mg $(OH)_2$ as filler materials were studied. Al_2O_3 has maximum particle size and density compared with the other fillers. SiC and B_4C has a good load withstanding capacity can be observed in various articles. It can be anticipated that, to prefer SiC and B_4C as filler material, since their combination of properties with the composites may enhance the mechanical properties.
ii. In the literature review, it is examined that E-glass/epoxy composite are subjected to various thermal conditions. Epoxy resin is reinforced with Woven carbon fiber, chopped E-glass, polyurethane adhesive etc. These are subjected to cryogenic treatment and evaluated their mechanical behavior. The temperature range is selected based on the applications of E-glass/epoxy composite in LNG carrier. E-glass fibers with epoxy resin may give better performance under these temperature conditions.
iii. From the review, it can be suggested that SiC and B_4C added with suitable proportion would be a better filler material for E-glass/epoxy composites in different structural application.
iv. Work has not done using E-glass/epoxy composites with SiC and B_4C filler material at cryogenic temperature. This gives a better platform to know the mechanical characteristics of E-glass/epoxy composite at cryogenic temperature and evaluated for its suitability in Cryogenic containment systems for LNG carriers.

REFERENCES

[1] Metin Sayer, "Elastic properties and buckling load evaluation of ceramic particles filled glass/epoxy composites" Elsevier, Composites: Part B 59, (2014), 12-20.

[2] Ramesh K. Nayak, Alina Dasha, B.C. Ray "Effect of epoxy modifiers (Al2O3/SiO2/TiO2) on mechanical performance of epoxy/glass fiber hybrid composites" Elsevier, Material Science 6: (2014) 1359 – 1364.

[3] P. K. Palani, M. Nanda kumar " Analysis Of Mechanical Properties Of Chopped Strand Mat E-Glass fibre Epoxy Resin Nanoclay Composites" The International Journal Of Engineering And Science (IJES), Volume 2, Pages 185-189, 2013.

[4] M. Sudheer, K. Hemanth, K. Raju, Thirumaleshwara Bhat "Enhanced Mechanical and Wear Performance of Epoxy/glass Composites with PTW/Graphite Hybrid Fillers" " Elsevier, Material Science 6 (2014) 975 – 987.

[5] S. Basavarajappa, S. Ellangovan "Dry sliding wear characteristics of glass–epoxy composite filled with silicon carbide and graphite particles "Elsevier, Wear 296 (2012) 491–496.

[6] M. Alagar, A. Ashok Kumar, K.P.O. Mahesh, K. Dinakaran, "Studies on thermal and morphological characteristics of E-Glass/Kevlar 49 reinforced siliconized epoxy composites." Elsevier, European Polymer Journal 36 (200) 2449-2454.

[7] J. Chen, A.J. Kinloch, S. Sprenger, A.C. Taylor "The mechanical properties and toughening mechanisms of an epoxy polymer modified with polysiloxane-based core-shell particles "Elsevier, Polymer 54 (2013) 4276 – 4289.

[8] Gaurav Agarwal, Amar Patnaik and Rajesh Kumar Sharma " Thermo-mechanical properties of silicon carbide-filled chopped glass fiber-reinforced epoxy composites" Springer, International Journal of Advanced Structural Engineering, 2013, 5:21.

[9] Sanghamitra Sethi, Bankim Chandra Ray, "An assessment of mechanical behavior and fractography study of glass/epoxy composites at different temperatures and loading speeds" Elsevier, Materials and Design 64 (2014) 160–165.

[10] K. Srinivas, M. S. Bhagyashekar, “Wear Behaviour of Epoxy Hybrid Particulate Composites “Elsevier, Procedia Engineering 97 (2014) 488 – 494.

[11] Bankim Chandra Ray & Dinesh Rathore, “A review on Mechanical Behaviour of FRP Composites at Different Loading speeds “Taylor &Francis, Critical Reviews in Solid State and Materials Sciences, 40:119–135, 2015.

[12] Juana Abenojar, Mariola Pantoja, Miguel Angel Martínez and Juan Carlos del Real, “Aging by moisture and/or temperature of epoxy/SiC composites: Thermal and mechanical properties “Journal of Composite Materials, 3 November 2014.

[13] S. Basavarajappa, S. Manjunath Yadav, Santosh Kumar, K.V. Arun & Narendranath S, “Abrasive Wear Behavior of Granite – filled Glass – Epoxy Composites by SiC Particles using Statistical Analysis, Taylor & Francis, Polymer – Plastics Technology and Engineering, 50:5, 516-524, 2011.

[14] M. S. Bhagyashekar, R. M. V. G. K. Rao”, Effects of Material and Test Parameters on the Wear Behavior of Particulate Filled Composites Part 1: SiC-Epoxy and Gr-Epoxy Composites”, Journal of Reinforced Plastics and Composites, Vol. 26, No. 17/2007

[15] Dinesh Kumar Rathore, Rajesh Kumar Prusty, Devalingam, Santhosh Kumar, Bankim Chandra Ray, “Mechanical performance of CNT-filled glass fiber/epoxy composite in in-situ elevated temperature environments emphasizing the role of CNT content” Elsevier, Composites: Part A 84 (2016) 364–376.

[16] T P Sathishkumar, S Satheeshkumar and J Naveen, “Glass fibre-reinforced polymer composites - a review “Journal of Reinforced Plastics and Composites 2014 33: 1258.

[17] M. A. Vadivelu, C. Ramesh Kumar & Girish M. Joshi, “Polymer composites for thermal management: a review “Taylor &Francis, Composite Interfaces, 23:9, 847-872.

[18] K.Devendra, T. Rangaswamy, “Evaluation of Thermal Properties of E-Glass/ Epoxy Composites Filled by Different Filler Materials” International Journal of Computational Engineering Research, Vol. 2 Issue.5, 2012.

[19] Wenying Zhou, Jing Zuo, Xiaoqian Zhang and Anning Zhou, “Thermal, electrical, and mechanical properties of hexagonal boron nitride-reinforced epoxy composites”, Journal of Composite Materials, 21 August 2013.

[20] V.C. Beber, B. Schneider & M. Brede, “Influence of Temperature on the Fatigue Behaviour of a Toughened Epoxy Adhesive”, Taylor & Francis, The Journal of Adhesion, 92:7-9, 778-794.

[21] Dalila Laouchedi, Boudjema Bezzazi & Chouaib Aribi, “Elaboration and characterization of composite material based on epoxy resin and clay fillers”, Elsevier, Journal of Applied Research and Technology, 2017.

[22] S. Rajesh, B. Vijaya Ramnath, C. Elanchezhian, N. Aravind, V. Vijai Rahul, S. Sathish, “Analysis of Mechanical Behaviour of Glass Fibre/ Al2O3- SiC Reinforced Polymer composites” Elsevier, Procedia Engineering 97 (2014) 598 – 606.

[23] Brahim Benmokrane, Ahmed H. Ali, Hamdy M. Mohamed, Adel ElSafty, Allan Manalo “Laboratory assessment and durability performance of vinyl-ester, polyester, and epoxy glass-FRP bars for concrete structures” Elsevier, Composites Part B 114 (2017) 163-174.

[24] L. M. Soffer & R. Molho, “Mechanical properties of epoxy resins and glass/epoxy composites at cryogenic temperatures, Journal of Macromolecular Science, 1:4, 709-739.

[25] Yuxin He, Guowei Chen, Li Zhang, Yafei Sang, Chang Lu, Dahu Yao and Yuqing Zhang, “Role of functionalized multiwalled carbon nanotubes on mechanical properties of epoxy-based composites at cryogenic temperature”, High Performance Polymers, 2014, Sage Publications, Vol. 26(8) 922–934.

[26] Morgan P. Hanson “Glass-, boron-, and graphite-filament-wound resin composites and liners for cryogenic pressure vessels” Taylor &Francis, Journal of Macromolecular Science, Part B, 1:4, 651-665.

[27] Hei-lam Ma, Zhemin Jia, Kin-tak Lau, Jinsong Leng, David Hui, “Impact properties of glass fiber/epoxy composites at cryogenic environment” Elsevier, Composites Part B 92 (2016) 210e217.

[28] M. Surendra Kumar, Neeti Sharma and B. C. Ray, “Microstructural and Mechanical Aspects of Carbon/Epoxy Composites at Liquid Nitrogen Temperature”, Journal of Reinforced Plastics and Composites, Vol.28, No. 16/2009, Sage Publications.

[29] Mohammad A Torabizadeh, “Tensile, compressive and shear properties of unidirectional glass/epoxy composites subjected to mechanical loading and low temperature services” India Journal of Engineering and Material Science, Vol 20, August 2013, pp. 299-309.

[30] H. Mivehchi, A. Varvani-Farahani, “The Effect of Temperature on Fatigue Strength and Cumulative Fatigue Damage of FRP Composites” Elsevier, Procedia Engineering 2 (2010) 2011–2020.

[31] Guozhi Ma, Ding Chen, Zhenhua Chen, Wei Li, “Effect of cryogenic treatment on microstructure and mechanical behaviors of the Cu-based bulk metallic glass matrix composite” Journal of Alloys and Compounds 505, (2010) 319-323.

[32] Chang Seon Bang, Jin Gyu Kim, Dai Gil Lee, “Performance improvement by glass fiber of adhesively bonded metal joints at the cryogenic temperature” Elsevier, Composites Structures 96 (2013) 321-331.

[33] Tomo Takeda, Weiwei Fan, Qing-Ping Feng, Shao-Yun Fu, Fumio Narita, Yasuhide Shindo, “Cryogenic mechanical properties of woven glass/epoxy composites modified with multi-walled carbon nanotube and n-butyl glycidyl ether under tensile static and cyclic loadings” Elsevier, Cryogenics 58 (2013) 33–37.

[34] Ilbeom Choi, Young Ho Yu, Dai Gil Lee, “Cryogenic sandwich-type insulation board composed of E-Glass/epoxy composite and polymeric foams” Elsevier, Composite Structures 102 (2013) 61–71.

[35] Young Ho Yu, Ilbeom Choi, Soohyun Nam, Dai Gil Lee, “Cryogenic characteristics of chopped glass fiber reinforced polyurethane foam” Elsevier, Composites Structures 107 (2014) 476-481.

[36] Tomo Takeda, Fumio Narita, Yasuhide Shindo, Kazuaki Sanada, “Cryogenic through-thickness tensile characterization of plain woven glass/epoxy composite

laminates using cross specimens: Experimental test and finite element analysis" Elsevier, Composites Part B 78 (2015) 42 - 49.

[37] Hei-lam Ma, Zhemin Jia, Kin-tak Lau, Jinsong Leng, David Hui "Impact properties of glass fiber/epoxy composites at cryogenic environment" Elsevier, Composites Part B 92 (2016) 210 - 217.

[38] Soohyun Nam, Young Ho Yu, Ilbeom Choi, Chang Seon Bang, Dai Gil Lee, "Fracture toughness improvement of polyurethane adhesive joints with chopped glass fibers at cryogenic temperatures" Elsevier, Composites: Part B 107 (2014)522-527.

[39] Zhixiong Wu, Jingwen Li, Chuanjun Huang, Laifeng Li "Effect of matrix modification on interlaminar shear strength of glass fibre reinforced epoxy composites at cryogenic temperature "Elsevier, Physics Procedia 67 (2015) 1068 – 1073.

[40] Dongyoung Lee, Ki Hyun Kim, Ilbeom Choi, Dai Gil Lee "Dynamic properties of the corrugated stainless steel membrane reinforced with the glass composite pressure resisting structure for LNG carriers", Elsevier, Composite Structures 107 (2014) 382–388.

[41] Bu Gi Kim, Dai Gil Lee, "Leakage characteristics of the glass fabric composite barriers of LNG ships", Elsevier, Composite Structures 86 (2008) 27–36.

[42] Chang Seon Bang, Choong Heum Park, Dai Gil Lee, "Optimum glass fibre volume fraction in the adhesive for the Al-SUS adhesively bonded joints at cryogenic temperatures," Elsevier, Composite Structures 108 (2014) 119–128.

[43] Fujun Xu, Wangxizi Fan, Yinnan Zhang, Yang Gao, Zhemin Jia, Yiping Qiu, David Hui, "Modification of tensile, wear and interfacial properties of Kevlar fibres under cryogenic treatment", Elsevier, Composites Part B (2016) 1-8.