Bulgarian Chemical Communications, Volume 55, Special Issue A (pp. 239-244) 2023 DOI: 10.34049/bcc.55.A.0036

Fabrication and performance evaluation of calcium bentonite-reinforced epoxy composites

V. Saxena*, U. Sharma, S. Jaiswal, P. K. Jayasawal, R. Patel

Department of Mechanical Engineering, Mahatma Jyotiba Phule, Rohilkhand University, Bareilly (U.P.), 243001 India

Received: February, 2023; Revised: March, 2023

In this study, bentonite-reinforced epoxy composites (ECs) were fabricated from different epoxy resins using a common amine functional hardener**.** Composite material is fabricated by two methods. One consists of epoxy (poly-epoxides) and hardener and the other consists of epoxy resin specimen mixed with HY 951 hardener. In the present work, composite material was fabricated by using unfilled epoxy resin and calcium bentonite-filled epoxy resin mixed with HY-951 hardener. ECs are known for their low cost, good properties, exceptional strength, super adhesion and good heat and weight resistance. The present experimental study focuses on the analysis of the material characteristics of unfilled epoxy resin and calcium bentonite-filled epoxy resin. The study revealed that tensile strength of calcium bentonite-filled epoxy resin is higher than that of unfilled epoxy resin. The energy absorbed by calcium bentonite-filled epoxy resin is greater than unfilled epoxy resin when performed by Izod test.

Keywords: Epoxy resins, calcium bentonite, epoxy composites, mechanical properties

INTRODUCTION

Bentonite is a clay mineral composed of two tetrahedral silica sheets and an octahedral aluminum sheet [1]. Natural calcium bentonite contains very low exchangeable sodium and large exchangeable calcium, although the proportions vary from one bentonite to another. It has a very low concentration of calcium **(**usually ≤0.5%) and has almost no pH value difference compared to salts (sodium, calcium), thus makes a small amount of grain distiller due to its low viscosity, but unfortunately is not very effective at protein removal [2]. Generally speaking, bentonite is usually formed by the erosion of volcanic ash in the presence of water.

Bentonite is a significant type of impure clay, characterized by its aluminum phyllosilicate adsorbent properties. It usually contains montmorillonite, arranged with gibbsite layers interspersed between silica layers, forming the basic structural unit (see Fig. 1).

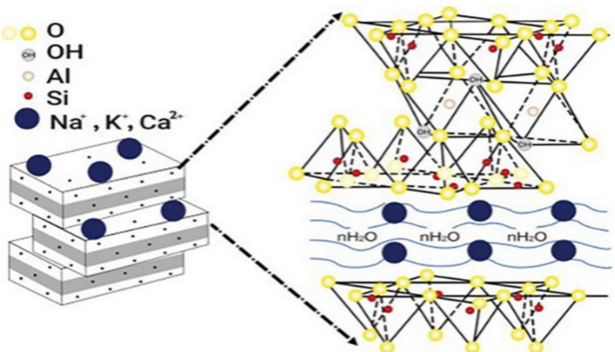

Fig. 1. Structure of bentonite

Replacements primarily occur within the octahedral layer (Mg^{2+}, Fe^{2+}) and, to a lesser extent, between the silicate layers (Al^{3+}/Si^{4+}). The composition of the clay is mainly attributed to the hydroxyl-alumino silicate structure. The crystal framework of clays is formed through the interaction between tetrahedral layers of silica and alumina octahedral sheets. Within their structure, partial exchange of Al^{3+} cations by Mg^{2+} or Fe^{2+} takes place, and this is balanced by the inclusion of metals such as Na, K, Mg, or Ca. The cation exchange capacity of the studied organoclays varies, depending on the type of organic counter-ions used [1].

In their study, Wang *et al*. conducted research on the preparation and properties of a bentonite-modified epoxy sheet molding compound. They reported that the inclusion of 1.5% BS (bentonite) in the BS/ESMC composite resulted in the highest recorded values for tensile strength, flexural strength, and impact strength, measuring 77.68 MPa, 230.75 MPa, and 108.07 MPa, respectively. Compared to the 0% bentonite/ESMC composite, the inclusion of bentonite increased the tensile strength, flexural strength, and impact strength by 24.15%, 26.56%, and 51.33%, respectively [3].

According to the study conducted by Jassim *et al*., the use of bentonite (a locally sourced raw material) in the preparation of ceramic bodies led to the formation of highly basic phases, namely mullite and cordierite, as confirmed by X-ray diffraction results [4].

* To whom all correspondence should be sent:
E-mail: vishal.saxena@mjpru.ac.in

Zimou *et al*. discovered that under pore water pressure conditions, the cyclic resistance of grouted specimens consisting solely of epoxy resin was found to be negligible.

However, the incorporation of 2.5% and 5% bentonite led to a significant increase in the cyclic strength of most of the grouted specimens [5].

In their investigation, T. Benelli *et al*. studied the preparation of two distinct organoclays obtained by modifying natural bentonite with nitrogen-based organic compounds, specifically BFTDA and APUA. These organoclays were subsequently utilized in the preparation of epoxy resin-based nanocomposites. The results showed that the incorporation of nanofillers did not have any adverse impact on the mechanical properties of the obtained nanocomposites [6].

Rubehghani *et al.* discovered that the energy absorption resulting from ballistic impact and the extent of damage were superior in composites containing cellulosic fibers compared to those with mineral fibers. The highest absorbed energy of ballistic impact (60.7 J) and the smallest damaged area (10.7 cm^2) were achieved when the composite included the highest concentration of cellulosic fibers (0.5%) and nano-bentonite (0.2%) [7]. In their research, Arif *et al.* examined the influence of BT (presumably bentonite) on the microstructure and physical behavior of SCs (likely referring to a specific material or composite). The results indicated that SCs exhibited a porous morphology, and the electrical percolation threshold was observed at 1.0 wt.% of BT. Additionally, the density and hydrophobicity of SCs increased progressively, with the highest values recorded at 2.0 wt.% of BT [8].

The study conducted by Jaidi *et al.* presents an eco-friendly approach for dispersing MWCNTs (multi-walled carbon nanotubes) into epoxy with the assistance of SCC (self-compacting concrete). This method led to the creation of CECs (carbon nanotube-epoxy composites) with enhanced dispersion and improved physical properties [9].

Jaidi *et al*. conducted a study on the wear behavior of EFNCs (presumably epoxy-ferrite nano-composites) and observed that it increased with the particle size of ferrite nanoparticles across all combinations of hydraulic end load and disc speeds [10].In their research, Jaidi *et al*. investigated the impact of PMMA (poly (methyl methacrylate)) mass uptake on various properties of E/PMMA blends. They found that PMMA mass uptake led to significant improvements in compression strength and resistance against thermo-oxidation. However, it resulted in a simultaneous decrease in Rockwell hardness (R scale), Charpy impact, and tensile strength of the E/PMMA blends. Furthermore, the incorporation of PMMA increased the thermo-oxidative stability, thermal properties, and char yield of all E/PMMA blends studied [11].

The researchers characterized the network structure of bentonite in both deionized water and salt water with calcium ions. The study found that the stability of the structure exhibited an initial increase followed by a decrease as the concentration of calcium ions increased. In deionized water, platelets were formed in an E-F mode, which then developed into E-E associations and denser aggregates with the gradual rise in calcium ion concentration. Moreover, the size of the network structure initially increased but subsequently slightly decreased. The findings of this study can serve as a useful guideline for controlling clay minerals in flotation processes [12].

MATERIAL AND METHOD

Materials

CY-230 epoxy resins, hardener HY-951, epoxy resin specimen, bentonite powder. The epoxy resins used for fabrication of composite have a density of 1.2 g/cm^3 and epoxy equivalent of 500 g/eq epoxy, respectively, whereas the density of hardener of HY 951 is 1.19 g/cm^3. Further, for the fabrication of the composite material a suitable particle size of bentonite powder is taken ranging from 0.8 μm to 2000 μm.

Fabrication of EC

Fabrication of ECs includes two types of casting. One consists of epoxy and hardener and the other consists of epoxy resin specimen mixed with HY-951 hardener.

Calculations

The calculation below gives the composition of material by first calculating its volume as 230.01 cm^3 using the dimension of length, breadth, and height. The density of the material is then calculated as 1.15 g/cm^3, which is used to find its mass as 264.51 g. subtracting the mass of 0.5% ferrite (1.32 g) and 9% hardener (21.05 g) gives the mass of the remaining epoxy as242.14 g.

Thus, the final composite of the material consists of 242.14g of epoxy resin, 21.05 g of hardener, and 1.32 g of ferrite.

Volume = L×B×H = 10.2×20.5×1.1 = 230.01 cm^3, density = M/V, therefore M = V×d =230.01×1.15 =264.51g, 0.5% ferrite 1.32 g, remaining volume = 264.51- 1.32 = 263.19 g, 9% hardener 21.05 g. Thus, the remaining epoxy = 263.19-21.05 = 242.14 g; the composition becomes:

epoxy resin - 242.14 g, hardener - 21.05 g and ferrite - 1.32 g.

Fabrication of epoxy resin specimen

First, we take the mould and pour the decided quantity of epoxy resin inside the mould and fill it with the given quantity and then pour the given quantity of hardener inside the mould. And then we heat the material for 1 hour at a temperature of 100 degrees Celsius.

After heating the material at 100 degrees Celsius for one hour, we take the material and stir it here for some time so that the material mixes itself homogeneously towards the whole composition.

The preparation process involves stirring and mixing the material at a specific temperature, after which it is poured into the mould and left undisturbed for a minimum of 24 hours. During this period, the material solidifies, allowing the specimen to be removed from the mould. Based on the calculations provided, the required amount of epoxy resin for the specimen is 242.14 g, while the necessary quantity of hardener is 21.05 g.

Fabrication of ECs material

First, we take the mould and pour the decided quantity of epoxy resin inside the mould and fill the mould with the given quantity and then pour the given quantity of hardener inside the mould. And then we heat the material for 1 hour at a temperature of 100 degree Celsius.

After heating the material at 100 degrees Celsius for one hour, we take the material and stir it here for some time so that the material mixes itself homogeneously towards the whole composition, now we stir it well so that its temperature falls. We stir it till the temperature reaches 45 degrees. And now we take the HY 951 hardener and put it inside the resin material and stir it well so that it mixes homogeneously. And then we pour the material inside the mould.

Araldite CY-230 is a liquid solvent-free epoxy resin. The treatment takes place at atmospheric pressure and at room temperature after adding the hardener. Usually, there is little healing of the contractions which can reduce more because of this bio-particles, China clay, etc. The addition of fillers is such that resin can be easily discolored. Mechanical, electrical properties and excellent resistance to chemical attack and atmosphere of fully cured composite are outstanding.

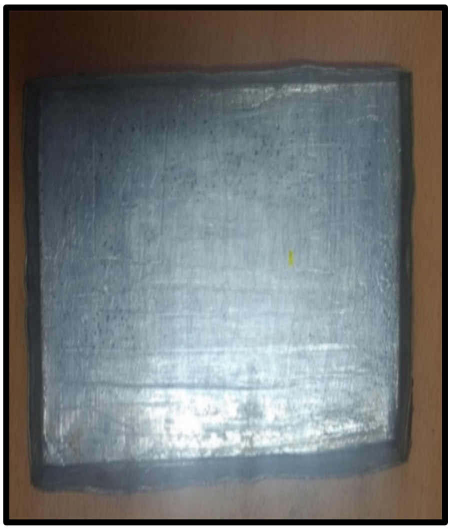

Fig. 2. Prepared mould

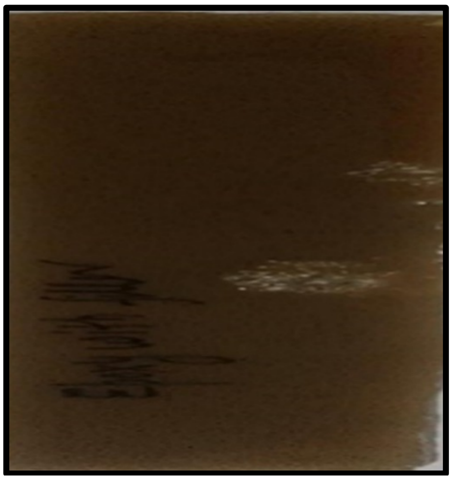

Fig. 3. Composite of epoxy resins and bentonite hardener

CY-230 epoxy resins (poly-epoxides)

Table 1 shows the physical and chemical properties of CY-230 rubber. It is a plastic condensation product bisphenol-A and epichlorohydrin, yellow-brown, odorless, tasteless and non-toxic. It has a viscosity of 1350-2000 mPa * s and specific gravity 1.1-1.2 g / cm^3at 25 ° C. Epoxy content 4.20-4.35 eq / kg, flash point 160^o. The resin appears to be a clear liquid.

Table 1. Physical and chemical properties of CY-230

Resin (Araldite CY-230)			
Physical properties		Yellow-brown, odorless, tasteless and completely nontoxic	
Chemical properties		Plasticized condensation product of bisphenol-A and epichlorohydrin.	
Viscosity at 25°C	ISO 2555	mPa*s	1350-2000
Specific gravity at 25°C	ISO 1675	g/cm³	1.1- 1.2
Appearance	Visual		Clear liquid
Epoxy content	ISO 3001	Eq/kg	4.20 -4.35
Flash point	DIN 51758	°C	160

Table 2. Chemical properties of HY- 951

Viscosity at 25°C	ISO 12058	mPa*s	10-20
Specific Gravity at 20°C	ISO 1675	g/cm³	0.98
Appearance	Visual		Clear liquid
Flash point	DIN 51758	°C	110

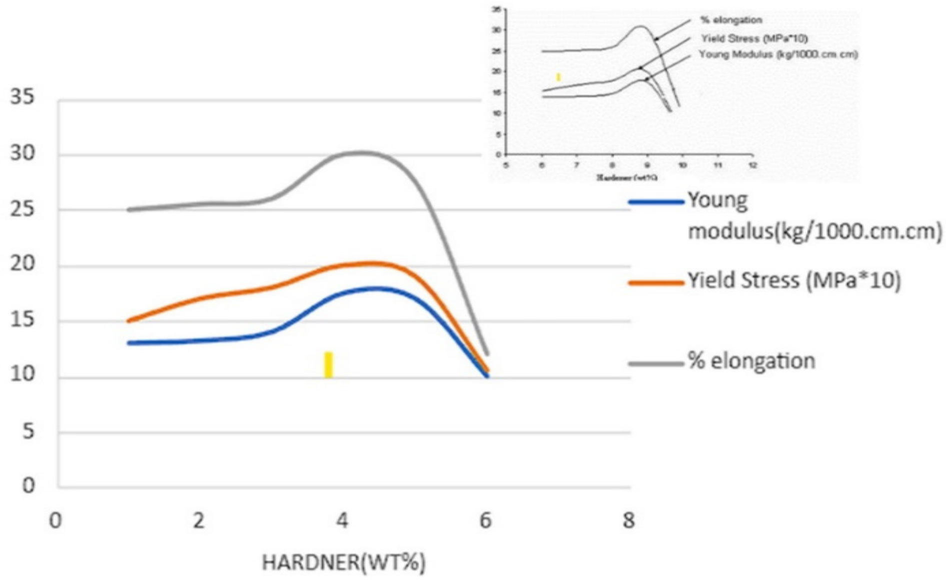

Fig. 4. Effect of wt.% of hardener HY951 on mechanical properties

Hardener HY-951

Araldite HY951 is an unfilled epoxy casting resin system known for its outstanding electrical properties and its ability to accommodate a high number of fillers.

Table 2 outlines the chemical properties of HY-951. The viscosity at 25ºC, as determined by the ISO 12058 standard, ranges from 10 to 20 MPa*s. The specific gravity at 20ºC, measured according to the ISO1675 standard, is 0.98 g/cm^3. HY-951 appears as a clear liquid, as determined by visual inspection. The flash point of HY-951, measured using the DIN 51758 standard, is 110º.

RESULTS AND DISCUSSION

Hardener HY-951

Figure 4 illustrates the correlation between the concentration of HY-951 and three mechanical properties: Young's modulus, yield stress, and % elongation. The graph shows the change in these properties as the concentration of HY-951 varies, with maximum & minimum values of 30 & 12 for % elongation, 20 & 11 MPa*10 for yield stress, & 17.5 &10 Kg/1000*cm^2 for Young’s modulus, respectively.

Results of unfilled epoxy resin tension test

Ultimate tensile strength (UTS) is a measure of the stress applied to a sample up to failure (fracture). provides important information on tensile properties, including yield point, tensile strength, and yield strength. The tensile strength of unfilled epoxy and calcium bentonite-filled epoxy composites was determined with a 100 kn universal testing machine of the transfer control type at a constant speed of 0.5 mm/min. Tensile stress-strain curves of unfilled epoxy resin (10% by weight HY-951 hardener and CY-230 resin) and calcium bentonite composite material provides some insight about material characteristics.

It is embedded in Fig. 5 that the material breaks at 12.5% strain and 0.045 KN/mm^2 stress with respect to strain. Its stress is greater than that of epoxy with hardener [13].

Maximum force: 4.815 kN; displacement at maximum force: 6.210 mm; maximum displacement: 7.480 mm; tensile strength: 0.048 kN/mm²; elongation: 5.000 %; reduction in area: 0.100 %.

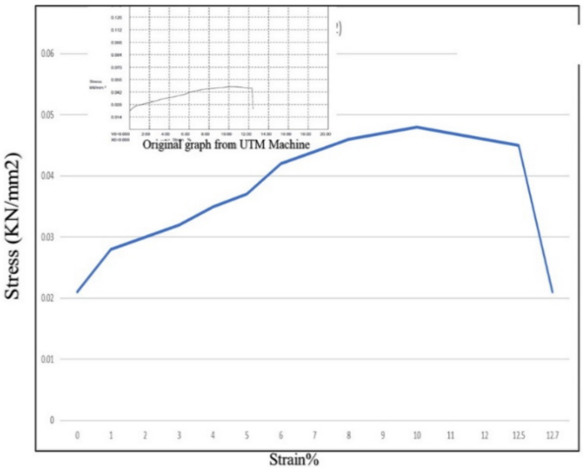

Fig. 5. Stress-strain graph of unfilled epoxy resin

Results of bentonite-filled epoxy resin tension test

In the tension test of epoxy resin filled with bentonite, the material's breaking point was observed to increase compared to the unfilled epoxy resin, making it suitable for high-tension applications. Figure 6 illustrates the behavior of the bentonite-filled epoxy, showing a breaking point at 8.20% strain and 53 MPa stress concerning strain.

Our research paper identified that the maximum tensile strength of the bentonite-filled epoxy was achieved at 1.5% bentonite content, measuring 77.68 MPa.

This represented a significant increase of 24.15% compared to the unmodified epoxy. However, in our specific study, the tensile strength was determined to be 53 MPa for the given composition [3]. Its stress is greater than epoxy $CaCO_3$nano cubes/epoxy composites and $CaCO_3$ nanorods/epoxy composites with hardener [14].

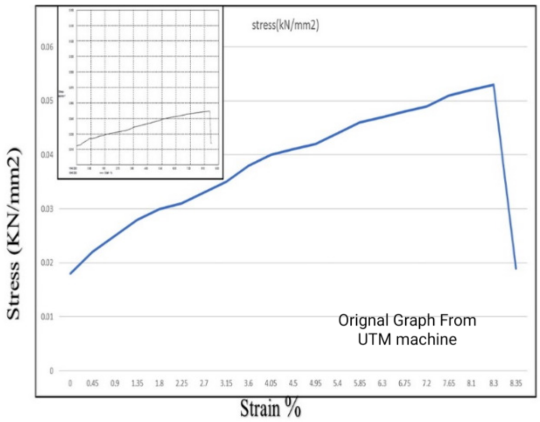

Fig. 6. Stress-strain graph of filled epoxy resin

Maximum force: 5.215 kN; displacement at maximum force: 8.420 mm; max. Displacement: 8.530 mm; tensile strength: 0.052 kn/mm²; elongation: 10.000 %; reduction in area: 1.000 %.

Impact test

The impact strength of epoxy resin and its composite specimens was tested using an impact testing machine. The apparatus consists of a pendulum whose mass is known and whose length falls from a certain height and strikes material samples drawn. The difference in energy transferred to the material can be determined by comparison of the height of the attacker before and after the break (energy absorbed in the punch). Therefore, Table 3 shows that calcium bentonite-filled epoxy has higher impact strength compared to calcium bentonite filled epoxy, clear epoxy. For example, an unprescribed epoxy resin has energy of 2.5 joules, calcium bentonite-filled epoxy. Resin energy absorbed is 3.8 joules. Therefore, we see that the energy absorption of epoxy resin filled with calcium bentonite increases.

Therefore, calcium bentonite filled with epoxy can be used in applications where strength is more important.

Table. 3. Energy absorbed by the specimen in Joule during Izod test

Unfilled Epoxy Resin	2.5
Calcium Bentonite filled Epoxy Resin	3.8

CONCLUSION

Bentonite composite is made with the help of

CY-230 epoxy resins (poly-epoxides), hardener HY-951 and bentonite powder. We made two types of composites- unfilled epoxy resin and calcium bentonite filled epoxy resin. We found that the tensile strength test and energy storage test is best performed by the bentonite-filled epoxy resin. Tensile strength test was performed on calcium bentonite filled epoxy resin and energy absorbed by specimen during Izod test was determined. Same test was performed on the unfilled epoxy resin and energy absorbed by specimen during Izod test was determined.

So, we conclude that calcium bentonite-filled epoxy resin is best at maximum tensile stress and toughness.

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