

# Mechanical Properties of Polymer Matrix Composites Developed from Fibre Glass (E-Class) and Bisphenol-A-Co-Epichlorohydrine

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## Abstract

Polymer matrix composites have been developed in this work using fibre glass (E-class) with epoxy resin and various grades of amine as curing agents. The polymer matrix composites were produced from two fibres (fibre glass and 3-dimensional cotton fabrics) and epoxy resins. The epoxy resin was produced by dissolving a measured quantity of solid and liquid bisphenol-a-co-epichlorohydrine in Acetone. Three different amines (diethylenetriamine (DETA), triethylenetetramine (TETA) and tetraethylene pentamine (TEPA)) were used as curing agents for the production work. The composites developed were subjected to tensile and hardness tests. The mechanical strength obtained is dependent on the grade and type of fibre used, the amine/epoxy ratio, epoxy/fibre weight ratio, thickness of the fibre and the use of additives as property modifiers. The results obtained showed that the tensile strength increases as the ratio of amine to epoxy ratio increases up to an optimal ratio of 0.17 when tetraethylenepentamine (TEPA) was used as the amine. The research work has also revealed that curing is best when tetraethylenepentamine was used as amine, followed by triethylenetetramine while diethylenetriamine produces weak materials due to the number of reactive sites present for cross-linking processes. Tensile strength reduces as the ratio of epoxy to fibre weight increased beyond the optimal ratio of 0.16 due to presence of more unreactive epoxy in the mixture. The polymer matrix composite (PMC) developed has a tensile strength of 90.93N/mm<sup>2</sup> and Rockwell Hardness Number of 23.4 (HRF).

*Keyword: amine/epoxy ratio, fibre glass, polymer matrix composites, tensile test, 3D woven fabric.*

## 1.0 Introduction

Polymer matrix composites are highly valued in industry as well as in the military because they have excellent structural benefits. For instance in the military, there has been significant increase in the use of glass fibres reinforced composites as structural materials in naval mini countermeasure surface ships to resist the underwater shock waves which could impact severe loading to naval ships structure [1].

Although several researches have been carried out on the development, characterization and dynamic behaviour of reinforced glass fibres [1-6], most of the applications are limited to

commercial use while the military applications are purely classified and unreported. Attempt is therefore made in this work to develop polymer matrix composites that could be used as protective wears in the military.

The most widely used composite materials have always been the polymer matrix systems because of their relative ease of processing, low density, chemical resistance, good mechanical and electrical properties, non-linear stress-strain relationship and high strain-failure [7].

More than eighty percent of all the reinforced polymer matrix composites have a thermoset matrix. Major applications include aerospace and electrical industries in helicopter firewalls, printed wiring boards and aerospace skin ribs [8].

The term matrix refers to the non-fibre phase of the composite. Its function is simply to aid in processing of fibres and act as a transfer medium from the environment to the fibres [7]. The matrix controls the physical properties. Mechanically, it sustains only a very small portion of the load. However, it protects the fibre from abrasive wear and corrosion. Matrix materials are available as either thermosetting or thermoplastic compounds.

There are five classes of thermosetting resins that serve the majority of the matrix applications for polymer matrix composites. They are epoxies, bismaleimide, phenolics, polyesters and polyimides [8]. A formulation may involve several resins combined with curing agents, catalysts, fillers and control agents, each contributing to the final matrix structure properties [10].

One of the key issues in the selection of a matrix is the maximum service temperature. The properties of a Polymer Matrix Composite (PMC) decreases with increasing temperature. A widely used method of establishing the heat resistance of polymers is to compute the glass transition temperature (T<sub>g</sub>) which is the temperature at which the polymer transits from a relatively rigid material to a rubbery one [8].

An important consideration in the selection of polymer matrices is their moisture sensitivity [8]. Resins tend to absorb water, which causes dimensional changes and reduction of elevated temperature strength and stiffness. The amount of moisture absorption, typically measured as percent weight gain, depends on the polymer and relative humidity.

Epoxy resins are the workhorse materials for airframe structures and other aerospace applications [8]. They produce composites with excellent structural properties. The maximum service temperature is affected by the reduced elevated temperature structural properties resulting from water absorption. A typical airframe service temperature limit is about 120°C [8].

Polymer matrix composites consist of fibres (discontinuous or dispersed phases) in a polymer matrix. The fibres are strong and stiff and have high specific strength-to-weight ratio and specific stiffness to weight ratio [7]. Apart from these qualities, reinforced plastic structures have improved fatigue strength, greater toughness, and high creep resistance than those of unreinforced plastics [8]. Available fibres for use are glass fibres, graphite fibres, boron fibres and aramides (Kevlar). The fibres in reinforced plastics by themselves have little structural value; they have stiffness in their longitudinal direction but no transverse stiffness. The plastic matrix is less strong and less stiff than the fibre, but it is tougher and often more chemically inert than the fibres. Reinforced plastics possess the advantages of each of the two constituents. The percentage of fibres (by volume) in reinforced plastics usually ranges from 10% to 60%. Practically, the percentage of fibre in a matrix is limited by the average distance between adjacent fibres or particles. The highest practical fibre content is 65 percent. Higher percentages generally result in lower structural properties [12].

The major advantage of polymer matrix composites is that of weight saving and low thermal expansion. However, they have a maximum service temperature of 315°C because the polymeric matrix loses strength when heated. Typical applications are found

in tennis rackets, skis, golf clubs, fishing poles, light weight armour plates and aerospace equipment [12].

The mechanical properties of polymers are not single valued functions of chemical nature of the macromolecules. They vary also with molecular weight, branching, cross-linking, crystalline, plasticizers, fillers, additives, orientation, and other consequence of processing history and sometimes with the thermal history of the particular sample. When all these variables are fixed for a particular specimen, it is observed that the properties of the material depend strongly on the temperature and time of testing compared to metals [13], [14]. This dependence is a consequence of the viscoelastic implication of polymers. The viscoelasticity implies that the material has the characteristics both of a viscous liquid which cannot support a stress without flowing and an elastic solid in which removal of the imposed stress results in complete recovery of the imposed deformation [14].

Based on its attributes as an engineering material, the potentials of polymer matrix composite for high impact resistance applications is being studied in this research work, with the possibilities of adopting composite materials for the production of engineering materials that can withstand impact loading.

## **2.0 Materials, equipment and experimental procedure**

### **2.1 Materials and equipment**

The main materials used in this investigation are fibre glass, 3-dimension woven fabrics (manufactured by NC University, USA), bisphenol-a-co-epichlorohydrine, diethylenetriamine, triethylenetetramine, tetraethylenepentamine, fillers (nitrile butlydene rubber, high density polyethylene (HDPE), acetone, mecaptopbenzothiazole (MBT), trimethylquinolone (TMQ), glass powder and sulphur.

The details of the sample descriptions are reflected below in tables 1 and 2 for fibre glass and 3D woven fabrics respectively.

**TABLE 1: SAMPLE DESCRIPTIONS - FIBRE GLASS**

Sample ID	Number of warp layers	x-yarn density/Layer (yarns/meter)	x-yarn linear density ( $\times 10^{-6}$ , kg/m)
1	3	320	735
2	3	560	1102
3	4	320	735
4	4	560	1102

**TABLE 2: FIXED PARAMETERS FOR FIBRE GLASS**

Fixed Parameters	
y-yarn density/layer (ends per meter)	240
y-yarn linear density ( $\times 10^{-6}$ , kg/m)	2275
z-yarn linear density ( $\times 10^{-6}$ , kg/m)	276
Weave structure	Plain weave
y-yarn and z-yarn arrangement	1 y/1z
x-,y-, and z-yarns material	E-fiberglass

x-yarn = weft

y-yarn = warp

**TABLE 3: LIST OF SAMPLES AND THEIR PARAMETERS – 3-DIMENSIONAL WOVEN FABRICS (COTTON)**

Sample ID	Number of Layers (y/x)	x-yarn density (threads/cm/layer)
13	2/3	3.68
14	2/3	4.14
15	2/3	4.46
16	2/3	4.92
17	$\frac{3}{4}$	3.68
18	$\frac{3}{4}$	4.14
19	$\frac{3}{4}$	4.46
20	$\frac{3}{4}$	4.92
21	4/5	3.68
22	4/5	4.14
23	4/5	4.46
24	4/5	4.92

The fixed parameters used for this experimental design as supplied by the manufacturer are:

Weave: 2x2 Basket

Linear Density x-yarns: 300 (g/km or tex)

Linear Density y-yarns: 698 (g/km or tex)

Linear Density z-yarns: 300 (g/km or tex)

The major items of equipment used for the study are as follows: Vacuum electrical oven (0-300°C), Hydraulic press with heating and cooling plates (craver, Compression moulding machine, 2- high rolling machine, Hounsfield Tensometer (20KN), Universal hardness testing machine.

## 2.2 Experimental procedure

Diluted bisphenol-a-co-epichlorohydrine mixed with a proportion of amine was poured on the fibre to achieve a single composite. The fibre was allowed to absorb the epoxy resin and then dried under atmospheric conditions for 24 hours for the initial stage of curing to evaporate the solvent (acetone).

The reaction was thermally activated in a vacuum oven set at 60°C for a period of 2

hours for the epoxy groups to react with the fibre and the amine hydroxyl group to diffuse into the environment.

Thereafter, samples were obtained by subjecting the samples in as-cast condition to hot pressing at 130°C under 10 bar for 10 minutes using a hydraulic press. Based on this procedure, a total number of 122 samples were produced by varying the volumes of bisphenol-a-co-epichlorohydrine and amine reacted with four different samples of fibre glass and twelve samples of 3-dimensional woven cotton fabrics.

All the one hundred and twenty two preliminary samples prepared were subjected to tensile tests in order to determine the

tensile strength with respect to the various compositions of epoxy and amines. From the various tests, it was discovered that the optimal ratio of epoxy to fibre and amine to epoxy are 0.16 and 0.17 respectively.

Additional ten samples of various sizes (50x100x5mm, 50x100x10mm, 50x100x15mm, 140x140x5mm, 140x140x10mm and 140x140x15mm) were prepared using epoxy/fibre weight ratio of 0.16 and amine/epoxy weight ratio of 0.17. The amine used for the optimized material was tetraethylenepentamine because of its excellent bonding characteristics which resulted in better strength as compared with other amines (diethylenetriamine and triethylenetetramine). The samples produced

were sandwiched with other polymer additives for an improved toughness, hardness and ballistic properties.

As a means of producing composite samples with increased toughness and smooth surfaces, the prepared polymer matrix composites were sandwiched with nitrile butylidene rubber, in the presence of high density polyethylene (HDPE), glass powders, mecaptobenzothiazole (MBT) which act as an accelerator, trimethylquinolone (TMQ) which act as an anti-degradation material. Sulphur was also used to aid the vulcanization process. The additive materials were formulated as shown in table 4 below.

**TABLE 4: FORMULATION OF ADDITIVES**

Materials	Weight by Part (g)	Total Weight (g)
High Density Polyethylene (HDPE)	70	210
Nitrile Butylidene Rubber (NBR)	30	90
Mecaptobenzothiazole (MBT)	2	6
Glass Powder (GP)	30	60
Sulphur	1.0	2
Trimethylquinolone (TMQ)	1.5	4.5

Compounding process was carried out using a 2-high rolling machine set at a temperature of 170°C. The rubber (NBR) was rolled thoroughly with the rolls at a temperature of 170°C until homogeneous mixture is obtained. Measured quantities of other components were added one after the other using table 4 until the compounding process was completed.

The PMC samples were then covered with the compounding materials with an average thickness of 3mm on both sides and 10mm along the edges. It was then placed in the prepared moulds before being taken to the hydraulic press for the post curing process. The samples were pressed at 150°C and a pressure of 7.5mpa for a period of 15mins using a compression moulding machine.

### 2.3 Mechanical tests

The mechanical properties of the various samples prepared were determined by tensile and hardness tests.

The tensile tests were carried out in accordance with International Standard ASTM D638-08 standard test method for tensile properties of plastics.

The test samples from various composites under study were cut into rectangular shapes with an average dimension of 15x40mm. The thickness varies slightly ranging from 2.0-6.6mm depending on the type of fibre used. The samples were mounted on the Hounsfield tensometer with a maximum capacity of 20KN. The various samples were loaded to fracture. After fracture, the elongation and tensile strength were recorded.

The hardness test was also carried out in line with international standard of measurement (ASTM D785) for determination of hardness number for plastic materials. Test specimen were cut from each of the samples being investigated. Each prepared specimen was secured on the machine platform (indent universal hardness testing machine) while the 1.5mm indenter with a load of 60kgf was applied gradually onto the specimen for the duration of 10 seconds. The load was then removed and the indent diameter read from the screen. The obtained diameter was loaded into the measuring system of the tester so as to display the hardness number on the screen. Three readings were taken from which an average value was obtained for each sample.

### 3.0 Results, analysis and discussion

#### 3.1 Results

##### 3.1.1 Tensile strength properties for fibre glass and 3-d cotton blended with epoxy resin

The tensile strength of the polymer matrix composites developed for various ratios of epoxy/fibre and amine/epoxy are reflected in table 5.

TABLE 5: TENSILE STRENGTH PROPERTIES FOR FIBRE GLASS AND 3-D COTTON BLENDED WITH EPOXY RESIN

Group no	Sample no	Epoxy g	Acetone ml	Amine used ml	Amine ml	Fibre wt g	Fibre Type	Fibre NO	Gauge Length mm	Specim width mm	Specim Thickn mm	Breaking Load KN	Extn mm	Crossect Area sq.mm	Tensile Strenght N/sq.mm	Ratio Epo/Fib	Ratio Am/Ep
A	1	3.00	15	DTA	0.50	12.28	FG	1	40	14.3	2.6	2.7	14.4	37.18	72.6197	0.24	0.17
	2	3.50	15	DTA	0.50	12.28	FG	1	40	14.3	2.0	2.1	15.0	28.60	73.4266	0.29	0.14
	3	4.00	15	DTA	0.50	12.28	FG	1	40	14.7	1.7	3.9	9.0	24.99	156.0624	0.33	0.13
	4	4.50	15	DTA	0.50	12.28	FG	1	40	15.0	2.0	4.1	13.0	30.00	136.6667	0.37	0.11
	5	5.00	15	DTA	0.50	12.28	FG	1	40	14.7	2.3	0.4	8.4	33.81	11.8308	0.41	0.10
B	6	2.50	10	DTA	0.50	12.28	FG	1	40	14.5	2.4	6.1	17.8	34.80	175.2874	0.20	0.20
	7	2.50	10	DTA	1.00	12.28	FG	1	40	14.0	2.2	2.3	14.6	30.80	74.6753	0.20	0.40
	8	2.50	10	DTA	1.50	12.28	FG	1	40	14.0	2.2	2.3	18.8	30.80	74.6753	0.20	0.60
	9	2.50	10	DTA	2.00	12.28	FG	1	40	14.0	2.3	2.0	20.0	32.20	62.1118	0.20	0.80
	10	2.50	10	DTA	2.50	12.28	FG	1	40	14.3	2.2	1.4	22.8	31.46	44.5010	0.20	1.00
C	11	2.50	10	TETA	0.50	12.28	FG	1	40	15.0	2.4	4.3	14.88	36.00	119.4444	0.20	0.20
	12	2.50	10	TETA	1.00	12.28	FG	1	40	15.0	2.2	2.3	17.76	33.00	69.6970	0.20	0.40
	13	2.50	10	TETA	1.50	12.28	FG	1	40	0.0				0.00	0.0000	0.20	0.60
	14	2.50	10	TETA	2.00	12.28	FG	1	40	14.5	2.2	0.45	13.08	31.90	14.1066	0.20	0.80
	15	2.50	10	TETA	2.50	12.28	FG	1	40	0.0				0.00	0.0000	0.20	1.00
D	16	2.50	10	TEPA	0.10	12.28	FG	1	40	15.0	2.7	2.7	14.4	40.5	66.6667	0.20	0.04
	17	2.50	10	TEPA	0.20	12.28	FG	1	40	15.0	2.8	2.6	20.8	42.00	61.9048	0.20	0.08
	18	2.50	10	TEPA	0.30	12.28	FG	1	40	15.0	2.4	3.3	18.4	36.00	91.6667	0.20	0.12
	19	2.50	10	TEPA	0.40	12.28	FG	1	40	14.0	2.5	3.4	13.8	35.00	97.1429	0.20	0.16
	20	2.50	10	TEPA	0.50	12.28	FG	1	40	14.0	2.7	4.2	13.2	37.80	111.1111	0.20	0.20
E	21	2.50	10	TEPA	0.50	12.28	FG	1	40	15.0	2.2	2.8	14.4	33.00	84.8485	0.20	0.20
	22	2.50	10	TEPA	1.00	12.28	FG	1	40	14.6	2.6	1.8	9.6	37.96	47.4183	0.20	0.40
	23	2.50	10	TEPA	1.50	12.28	FG	1	40	15.0	2.2	1.8	13.2	33.00	54.5455	0.20	0.60
	24	2.50	10	TEPA	2.00	12.28	FG	1	40	17.4	2.5	2.8	10.6	43.50	64.3678	0.20	0.80
	25	2.50	10	TEPA	2.50	12.28	FG	1	40	16.6	2.4	1.7	18.6	39.84	42.6707	0.20	1.00
F	26	3.00	15	TEPA	0.50	12.28	FG	1	40	16.0	2.2	5.7	13.2	35.20	161.9318	0.24	0.17
	27	3.50	15	TEPA	0.50	12.28	FG	1	40	17.5	3.0	6.9	18.8	52.50	131.4286	0.29	0.14
	28	4.00	15	TEPA	0.50	12.28	FG	1	40	0.0				0.00	0.0000	0.33	0.13
	29	4.50	15	TEPA	0.50	12.28	FG	1	40	16.3	2.6	5.3	17.4	42.38	125.0590	0.37	0.11
	30	5.00	15	TEPA	0.50	12.28	FG	1	40	14.5	2.6	2.0	15.6	37.70	53.0504	0.41	0.10
G	31	2.50	10	TEPA	0.50	12.28	FG	1	40	0.0						0.20	0.20
	32	2.50	10	TEPA	1.00	12.28	FG	1	40	15.0	1.6	0.5	6.96	24.00	20.8333	0.20	0.40
	33	2.50	10	TEPA	1.50	12.28	FG	1	40	14.3	1.6	0.3	6.96	22.88	13.1119	0.20	0.60
	34	2.50	10	TEPA	2.00	12.28	FG	1	40	15.0	1.2	2.2	18.96	18.00	122.2222	0.20	0.80
	35	2.50	10	TEPA	2.50	12.28	FG	1	40	15.0	2.6	4.2	13.68	39.00	107.6923	0.20	1.00
H	36	2.50	10	DTA	0.50	15.48	FG	2	40	12.0	3.0	3.0	14.4	36.00	83.3333	0.16	0.20
	37	2.50	10	DTA	1.00	15.48	FG	2	40	15.0	3.0	1.9	13.4	45.00	42.2222	0.16	0.40
	38	2.50	10	DTA	1.50	15.48	FG	2	40	14.0	2.7	4.8	13.2	37.80	126.9841	0.16	0.60
	39	2.50	10	DTA	2.00	15.48	FG	2	40	16.0	3.2	3.3	12.2	51.20	64.4531	0.16	0.80
	40	2.50	10	DTA	2.50	15.48	FG	2	40	14.3	3.0	3.5	15.6	42.90	81.5851	0.16	1.00

Table cont'd.

Group	Sample	Epoxy	Acetone	Amine	Amine	Fibre	Fibre	Fibre	Gauge	Specim	Specim	Breaking	Extn	Crossect	Tensile	Ratio	Ratio
no	no	g	ml	used	ml	wt	Type	NO	Length	width	Thickn	Load	mm	Area	Strenght	Epo/Fib	Am/Ep
									mm	mm	mm	KN	mm	sq.mm	N/sq.mm		
I	41	3.00	25	DTA	0.50	15.48	FG	2	40	0.0				0.00	0.0000	0.19	0.17
	42	3.50	25	DTA	0.50	15.48	FG	2	40	0.0				0.00	0.0000	0.23	0.14
	43	4.00	25	DTA	0.50	15.48	FG	2	40	13.0	2.5	4	15.36	32.50	123.0769	0.26	0.13
	44	4.50	25	DTA	0.50	15.48	FG	2	40	14.7	2.4	8.2	15.36	35.28	232.4263	0.29	0.11
	45	5.00	25	DTA	0.50	15.48	FG	2	40	15.4	2.4	7.2	14.16	36.96	194.8052	0.32	0.10
J	46	3.00	25	TETA	0.50	15.58	FG	2	40	15.0	3.0	5.8	13.2	45.00	128.8889	0.19	0.17
	47	3.50	25	TETA	0.50	15.58	FG	2	40	15.0	2.4	5.8	17.4	36.00	161.1111	0.22	0.14
	48	4.00	25	TETA	0.50	15.58	FG	2	40	14.5	3.0	5.2	13.2	43.50	119.5402	0.26	0.13
	49	4.50	25	TETA	0.50	15.58	FG	2	40	14.5	3.0	5.8	14.4	43.50	133.3333	0.29	0.11
	50	5.00	25	TETA	0.50	15.58	FG	2	40	14.0	3.2	4.8	16.8	44.80	107.1429	0.32	0.10
K	51	2.50	10	TETA	0.50	15.48	FG	2	40	16.0	2.8	6.1	16.2	44.80	136.1607	0.16	0.20
	52	2.50	10	TETA	1.00	15.48	FG	2	40	0.0	0.0			0.00	0.0000	0.16	0.40
	53	2.50	10	TETA	1.50	15.48	FG	2	40	17.4	2.5	2.2	20.88	43.5	50.5747	0.16	0.60
	54	2.50	10	TETA	2.00	15.48	FG	2	40	0.0	0			0		0.16	0.80
	55	2.50	10	TETA	2.50	15.48	FG	2	40	0.0	0			0		0.16	1.00
L	56	5.25	30	TEPA	0.50	15.48	FG	2	40	14.4	3.0	7.0	16.8	43.20	162.0370	0.34	0.10
	57	5.50	30	TEPA	0.50	15.48	FG	2	40	13.6	3.2	7.5	19.2	43.52	172.3346	0.36	0.09
	58	5.75	30	TEPA	0.50	15.48	FG	2	40	14.4	3.4	7.2	19.2	48.96	147.0588	0.37	0.09
M	59	6.00	30	TEPA	0.50	15.48	FG	2	40	16.0	3.4	4.9	16.0	54.40	90.0735	0.39	0.08
	60	6.25	30	TEPA	0.50	15.48	FG	2	40	14.6	3.1	7.5	14.8	45.26	165.7092	0.40	0.08
N	61	3.00	25	TEPA	0.50	15.48	FG	2	40	14.4	2.2	8.2	13.7	31.68	258.8384	0.19	0.17
	62	3.50	25	TEPA	0.50	15.48	FG	2	40	14.6	3.0	6.8	15.1	43.80	155.2511	0.23	0.14
	63	4.00	25	TEPA	0.50	15.48	FG	2	40	14.0	3.1	7.1	17.4	43.40	163.5945	0.26	0.13
	64	4.50	25	TEPA	0.50	15.48	FG	2	40	13.7	3.2	8.7	16.9	43.84	198.4489	0.29	0.11
	65	5.00	25	TEPA	0.50	15.48	FG	2	40	16.0	3.0	6.7	11.8	48.00	139.5833	0.32	0.10
O	66	2.50	10	TEPA	0.50	15.48	FG	2	40	16.2	2.0	1.5	23.0	32.40	46.2963	0.16	0.20
	67	2.50	10	TEPA	1.00	15.48	FG	2	40	13.7	2.0	2.4	21.6	27.40	87.5912	0.16	0.40
	68	2.50	10	TEPA	1.50	15.48	FG	2	40	16.0	2.5	3.8	17.3	40.00	95.0000	0.16	0.60
	69	2.50	10	TEPA	2.00	15.48	FG	2	40	0.0				0.00	#DIV/0!	0.16	0.80
	70	2.50	10	TEPA	2.50	15.48	FG	2	40	14.5	2.5	7.5	13.4	36.25	206.8966	0.16	1.00
P	71	3.00	15	TEPA	0.50	18.25	FG	3	40	16.0	4.4	8.3	22.8	70.40	117.8977	0.16	0.17
	72	4.00	15	TEPA	0.50	18.25	FG	3	40	13.8	4.5	6.7	21.6	62.10	107.8905	0.22	0.13
	73	5.00	15	TEPA	0.50	18.25	FG	3	40	14.5	4.8	7.3	19.2	69.60	104.8851	0.27	0.10
	74	6.00	15	TEPA	0.50	18.25	FG	3	40	13.3	4.7	3.5	16.8	62.51	55.9910	0.33	0.08
	75	7.00	15	TEPA	0.50	18.25	FG	3	40	14.0	5.0	1.1	13.2	70.00	15.7143	0.38	0.07
Q	76	2.50	10	TEPA	0.50	5.17	3DC	13	40	15.7	1.4	0.4	10.8	21.98	18.1984	0.48	0.20
	77	3.00	10	TEPA	0.50	5.17	3DC	13	40	15.3	2.3	0.6	13.8	35.19	17.0503	0.58	0.17
	78	3.50	10	TEPA	0.50	5.17	3DC	13	40	15.0	2.8	0.4	15.4	42.00	9.5238	0.68	0.14
	79	4.00	10	TEPA	0.50	5.17	3DC	13	40	16.0	3.0	0.5	22.4	48.00	10.4167	0.77	0.13
	80	4.50	10	TEPA	0.50	5.17	3DC	13	40	16.0	1.7	0.6	16.6	27.20	22.0588	0.87	0.11

Table cont'd.

Group	Sample	Epoxy	Acetone	Amine	Amine	Fibre	Fibre	Fibre	Gauge	Specim	Specim	Breaking	Extn	Crossect	Tensile	Ratio	Ratio
no	no	g	ml	used	ml	wt	Type	NO	Length	width	Thickn	Load	mm	Area	Strenght	Epo/Fib	Am/Ep
									mm	mm	mm	KN	mm	sq.mm	N/sq.mm		
	81	5.00	10	TEPA	0.50	5.17	3DC	13	40	15.3	3.5	0.2	25.2	53.55	3.7348	0.97	0.10
	82	5.50	10	TEPA	0.50	5.17	3DC	13	40	15.5	3.0	0.4	25.4	46.50	8.6022	1.06	0.09
	83	6.00	10	TEPA	0.50	5.17	3DC	13	40	16.4	4.0	0.4	25.6	65.60	6.0976	1.16	0.08
	84	6.50	10	TEPA	0.50	5.17	3DC	13	40	14.4	3.2	0.5	10.8	46.08	10.8507	1.26	0.08
	85	7.00	10	TEPA	0.50	5.17	3DC	13	40	17.4	3.5	0.7	16.8	60.90	11.4943	1.35	0.07
R	86	11.00	25	TEPA	0.50	5.17	3DC	13	40	15.0	4.0	0.8	8.4	60.00	13.3333	2.13	0.05
	87	12.00	25	TEPA	0.50	5.17	3DC	13	40	15.6	3.2	1.0	8.4	49.92	20.0321	2.32	0.04
	88	13.00	25	TEPA	0.50	5.17	3DC	13	40	14.4	3.0	0.8	6.8	43.20	18.5185	2.51	0.04
	89	14.00	25	TEPA	0.50	5.17	3DC	13	40	15.0	2.3	1.0	1.2	34.50	28.9855	2.71	0.04
	90	15.00	25	TEPA	0.50	5.17	3DC	13	40	16.0	3.2	1.0	7.2	51.20	19.5313	2.90	0.03
	91	16.00	25	TEPA	0.50	5.17	3DC	13	40	16.0	3.1	1.0	7.2	49.60	20.1613	3.09	0.03
	92	17.00	25	TEPA	0.50	5.17	3DC	13	40	16.2	4.0	0.8	10.2	64.80	12.3457	3.29	0.03
	93	18.00	25	TEPA	0.50	5.17	3DC	13	40	15.7	3.0	0.5	4.6	47.10	10.6157	3.48	0.03
	94	19.00	25	TEPA	0.50	5.17	3DC	13	40	16.0	4.0	0.4	3.6	64.00	6.2500	3.68	0.03
S	95	10.00	25	TEPA	1.00	5.49	3DC	14	40	14.4	4.5	0.6	9.4	64.80	9.2593	1.82	0.10
	96	11.00	25	TEPA	1.00	5.49	3DC	14	40	15.3	3.2	0.6	5.2	48.96	12.2549	2.00	0.09
	97	12.00	25	TEPA	1.00	5.49	3DC	14	40	16.7	4.3	0.8	11.0	71.81	11.1405	2.19	0.08
	98	13.00	25	TEPA	1.00	5.49	3DC	14	40	15.3	3.3	0.3	16.0	50.49	5.9418	2.37	0.08
	99	14.00	25	TEPA	1.00	5.49	3DC	14	40	17.4	4.7	0.8	19.6	81.78	9.7823	2.55	0.07
T	100	10.00	25	TEPA	0.50	5.49	3DC	14	40	15.5	2.8	1.1	8.6	43.40	25.3456	1.82	0.05
	101	11.00	25	TEPA	0.50	5.49	3DC	14	40	15.2	2.5	0.6	7.2	38.00	15.7895	2.00	0.05
	102	12.00	25	TEPA	0.50	5.49	3DC	14	40	15.5	2.3	0.9	8.4	35.65	25.2454	2.19	0.04
	103	13.00	25	TEPA	0.50	5.49	3DC	14	40	16.0	3.0	0.5	2.4	48.00	10.4167	2.37	0.04
	104	14.00	25	TEPA	0.50	5.49	3DC	14	40	15.6	3.0	0.9	13.2	46.80	19.2308	2.55	0.04
	105	15.00	25	TEPA	0.50	5.49	3DC	14	40	18.0	3.0	0.4	20.4	54.00	7.9630	2.73	0.03
	106	16.00	25	TEPA	0.50	5.49	3DC	14	40	15.2	2.8	0.9	15.6	42.56	21.1466	2.91	0.03
	107	17.00	25	TEPA	0.50	5.49	3DC	14	40	14.5	4.0	0.9	19.2	58.00	15.5172	3.10	0.03
	108	18.00	25	TEPA	0.50	5.49	3DC	14	40	15.7	4.5	0.6	21.8	70.65	8.4926	3.28	0.03
	109	19.00	25	TEPA	0.50	5.49	3DC	14	40	15.5	5.4	0.5	25.0	83.70	5.9737	3.46	0.03
U	110	10.00	20	TEPA	0.50	6.4	3DC	17	40	15.2	4.0	0.9	13.8	60.80	14.8026	1.56	0.05
	111	11.00	20	TEPA	0.50	6.4	3DC	17	40	15.5	5.0	0.7	19.2	77.50	9.0323	1.72	0.05
	112	12.00	20	TEPA	0.50	6.4	3DC	17	40	15.5	4.8	0.8	21.0	74.40	10.7527	1.88	0.04
	113	13.00	20	TEPA	0.50	6.4	3DC	17	40	17.4	5.3	0.8	22.6	92.22	8.6749	2.03	0.04
	114	14.00	20	TEPA	0.50	6.4	3DC	17	40	16.3	4.3	0.8	22.8	70.09	11.4139	2.19	0.04
V	115	11.00	25	TEPA	1.00	6.86	3DC	19	40	15.7	5.0	0.8	8.6	78.50	10.5732	1.60	0.09
	116	12.00	25	TEPA	1.00	6.86	3DC	19	40	15.3	4.7	1.0	8.4	71.91	13.9063	1.75	0.08
	117	13.00	25	TEPA	1.00	6.86	3DC	19	40	16.5	3.5	0.6	10.8	57.75	10.3896	1.90	0.08
W	118	10.00	25	TEPA	1.00	7.25	3DC	21	40	15.8	6.0	0.5	10.8	94.80	5.2743	1.38	0.10
	119	11.00	25	TEPA	1.00	7.25	3DC	21	40	17.0	6.0	0.3	15.0	102.00	2.9412	1.52	0.09
X	120	12.00	25	TEPA	1.00	7.25	3DC	21	40	17.3	5.2	0.6	8.6	89.96	6.6696	1.66	0.08
	121	13.00	25	TEPA	1.00	7.25	3DC	21	40	17.0	6.6	0.8	2.6	112.20	7.1301	1.79	0.08
	122	14.00	25	TEPA	1.00	7.25	3DC	21	40	16.0	4.2	0.4	14.8	67.20	5.9524	1.93	0.07

### 3.1.2 Tensile strength for fibre glass and epoxy resin rolled with nitrile butyldene rubber

Table 6 shows the tensile properties of the polymer matrix composite compounded with

nitrile butyldene rubber and high density polyethylene at an optimal ratio of epoxy/fibre ratio of 0.16.

TABLE 6: TENSILE STRENGTH PROPERTIES FOR FIBRE GLASS AND EPOXY ROLLED WITH NBR(COMPOUNDED)

Sample no	Epoxy	Aceton	Amine used	Amine	Fibre wt	Fibre Type	Fibre no	Gaug Length	Specim width	Specime Thicknes	Breaking Load	Extension	Crosed Area	Tensile Strenght	Ratio Epoxy/Fibre	Ratio Amine/Et
	g	ml		ml	g			mm	mm	mm	KN	mm	sq.mm	N/sq.mm		
1	7.50	45	TEPA	1.50	46.44	FG2	2	40	9.0	8	9.2	26.8	72	127.7778	0.16	0.20
2	7.50	45	TEPA	1.50	46.44	FG2	2	40	11.2	8.5	9.5	26.4	95.2	99.7899	0.16	0.20
3	7.50	45	TEPA	1.50	46.44	FG2	2	40	10.5	5.7	9.0	26.7	59.85	150.3759	0.16	0.20
4	7.50	45	TEPA	1.50	46.44	FG2	2	40	11.4	6.4	9.4	25.2	72.96	128.8377	0.16	0.20
5	8.76	45	TEPA	1.50	54.75	FG3	3	40	9.0	6.0	8.3	10.8	54	153.7037	0.16	0.17
6	8.76	45	TEPA	1.50	54.75	FG3	3	40	9.2	7.3	8.4	10.6	67.16	125.0744	0.16	0.17
7	11.75	45	TEPA	2.00	73.54	FG4	4	40	13.7	6.5	9.2	12.5	89.05	103.3127	0.16	0.17
8	11.75	45	TEPA	2.00	73.54	FG4	4	40	13.4	6.0	9.5	13.2	80.4	118.1592	0.16	0.17
9	11.75	45	TEPA	2.00	73.54	FG4	4	40	15.2	8.4	9.4	17.5	127.7	73.6216	0.16	0.17
10	11.75	45	TEPA	2.00	73.54	FG4	4	40	15.3	5.5	9.0	17.0	84.15	106.9519	0.16	0.17

### 3.1.3 Results of hardness property of polymer matrix composites

The hardness properties (Hardness Rockwell value) of the polymer matrix composite are indicated in table 7.

TABLE 7: HARDNESS ROCKWELL VALUE(HRF) OF POLYMER MATRIX COMPOSITE

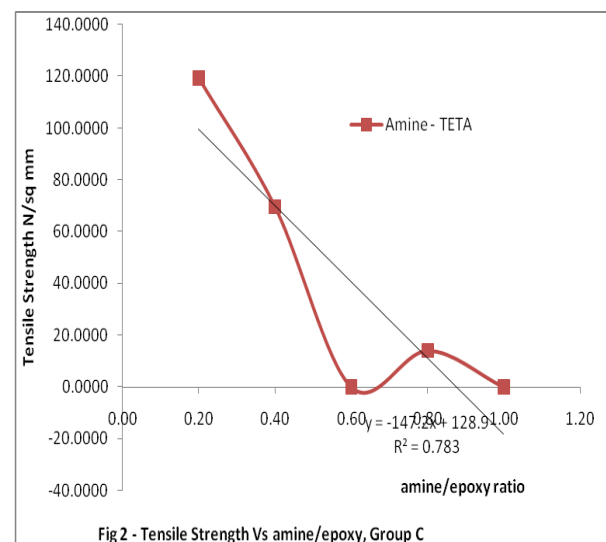
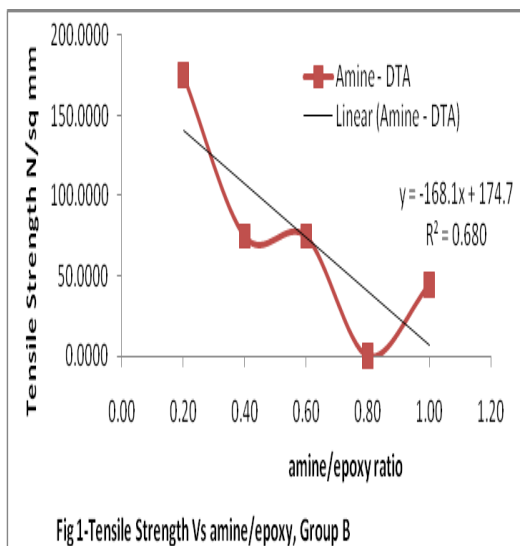
Group no	Fibre Type	Fibre NO	Sample 1	Sample 2	Sample 3	Sample Average
A	FG	2	23.00	23.4	23.8	23.4
B	FG	2	23.80	24	23.6	23.8
C	FG	3	23.80	23.4	23.6	23.6
D	FG	4	23.01	23.4	23.4	23.3

## 3.2 Discussion of results

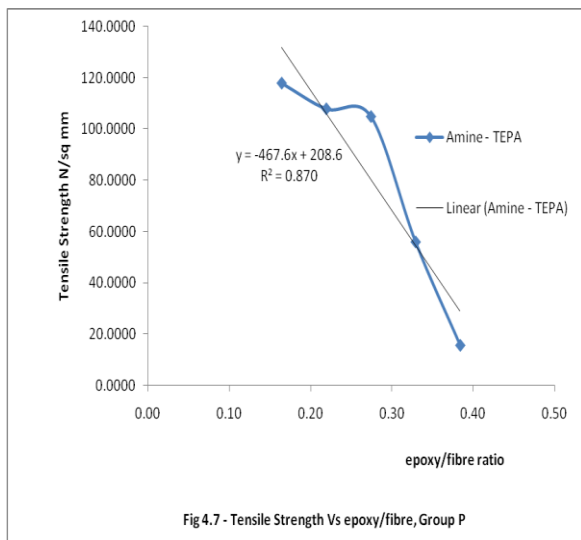
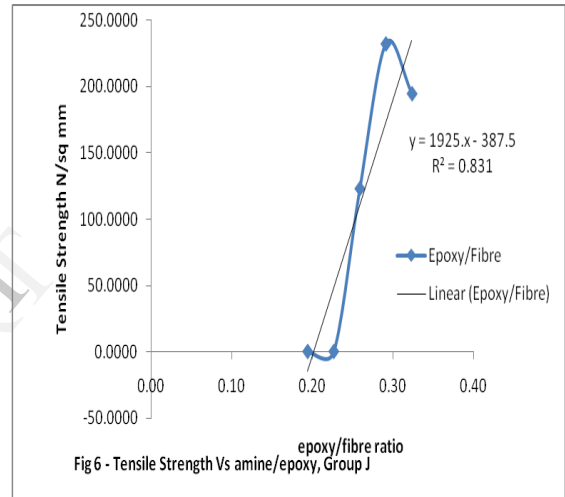
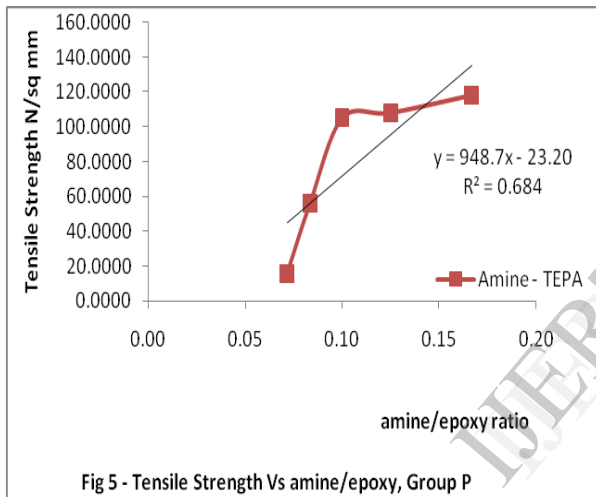
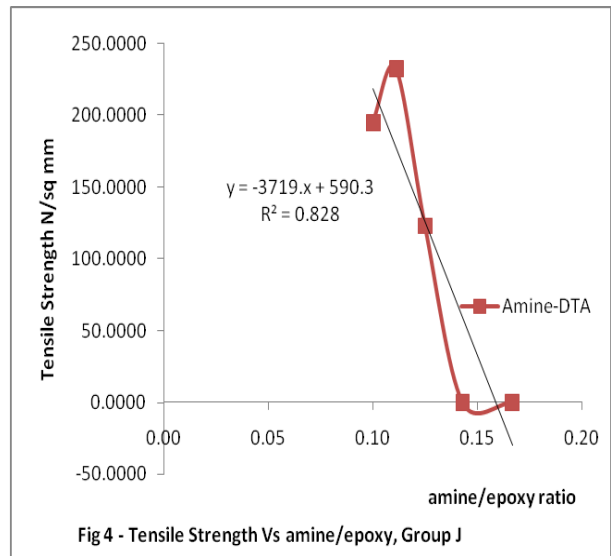
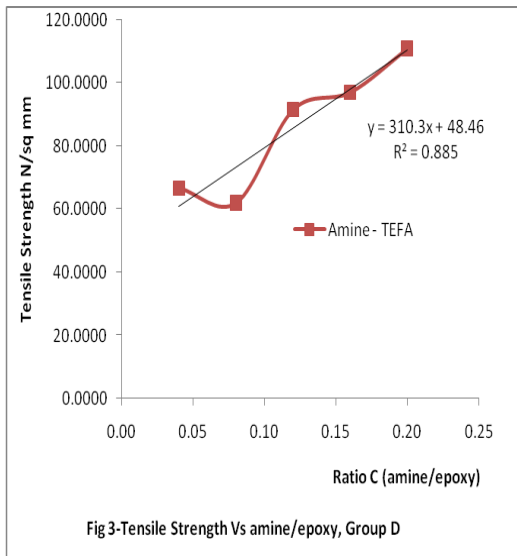
### 3.2.1 Tensile strength against ratios and thickness of fibres

The behaviour of the developed polymer matrix composites were studied by plotting

graphs of tensile strength against the various weight ratios of amine/epoxy and epoxy/fibre for selected representative groups. The resulted graphs are displayed in fig 1 through Fig 7.







The tensile strength of the polymer matrix composites is heavily dependent on the type of amine used and the grade of fibre. When diethylenetriamine (DETA) was used, the tensile strength decreases as the ratio of amine to epoxy increases for all the fibre types used

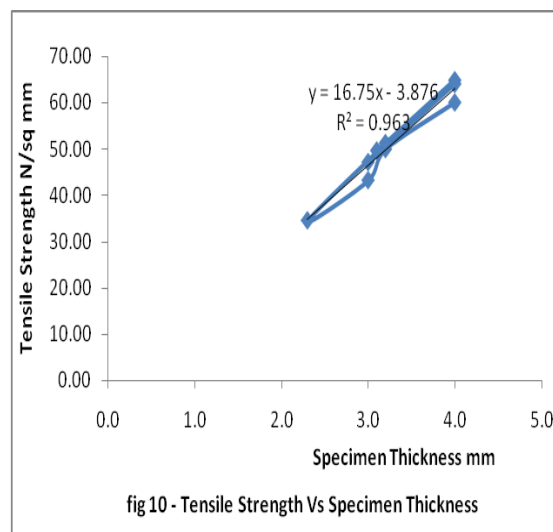
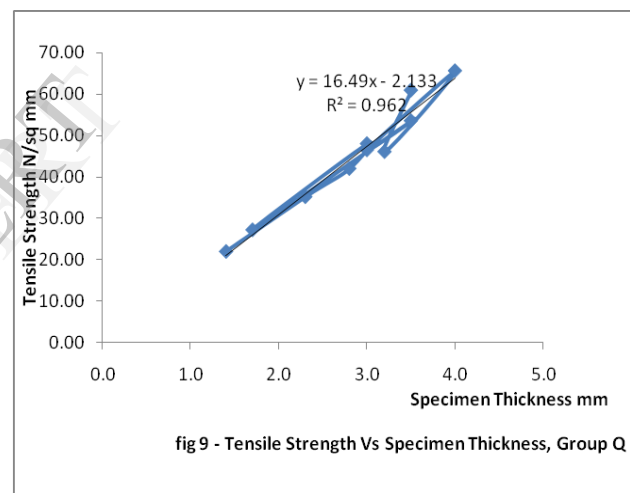
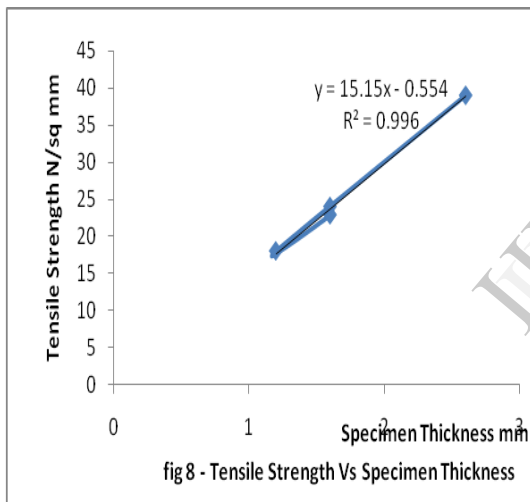
in the research work. The relationship can be expressed as;  
 $Y = -3719.0X + 590.3; N/mm^2$ ,  
 for  $0 \leq x \leq 0.2$   
 where; Y = Tensile strength  
 X = Ratio of amine to epoxy.

The behaviour of polymer matrix composites to tetraethylenepentamine (TEPA) was quite different. Tensile strength increases as the amine to epoxy (A/E) ratio increase up to an optimal ratio of 0.2 (fig 3 and fig 3). The regression equation is expressed as;  
 $Y=948.7X+23.20$ ;  $N/mm^2$   
 for  $0 \leq x \leq 0.2$

The research work shows that curing is best with tetraethylenepentamine (TEPA), followed by triethylenetetramine (TETA) while diethylenetriamine produces weak materials. Tetraethylenepentamine has more reactive sites with eight active hydrogen atoms and five active nitrogen atoms for cross-linking, unlike triethylenetetramine which has six reactive hydrogen atoms and four reactive nitrogen atoms for cross-linking. The diethylenetriamine has only four reactive hydrogen sites and three reactive nitrogen atoms. The more the cross-linking formed, the better the rate of curing and the resulting

strength of polymer formed. The 3-dimensional cotton did not respond to amine treatment as much as the fibre glass did. This is indicated in table 4 with much lower values for tensile properties as compared with that of fibre glass.

Figure 7 shows that the tensile strength tends to decrease as the ratio of epoxy to fibre weight (E/F) increases for all the samples tested using TEPA as amine. However, it increases when DTA was employed (fig 6). The work had shown that the optimal mixture ratio for epoxy/fibre weight is 0.16 after which the behaviour completely changed due to presence of more unreactive epoxy in the mixture. The various regression values obtained can be used to predict or model the behaviour at different mixture ratios. Figure 8 through 10 show that the tensile strength increased with the thickness for the majority of the samples tested.



Tensile strength increases with the molecular weight of the polymer, that explains why tetraethylenepentamine which has the highest cross linking network of polymer produced the highest strength. Above the value of the optimal ratio, the amine becomes unreactive and results in weak composites. With the increase in the volume of epoxy used and the thickness of fibres, there is a progressive improvement in the tensile strength of the formulated composites due to the increase in molecular weight.

The tensile properties of the compounded materials containing high density polyethylene (HDPE) and nitrile-butadiene rubber (NBR) did not show remarkable difference from the ones without the compounding materials. This is expected because tensile strength depends solely on the strength of the fibre and not on the compounded material (NBR and HDPE).

### 3.2.2 HARDNESS PROPERTY

The results of hardness values are indicated in table 7. The average Rockwell Hardness number (HRF) using scale 'f' is 23.4. This falls within an acceptable standard for polymers [8].

### 4.0 CONCLUSION

Polymer matrix composite has been successfully formulated in this work with the use of fibre glass of E-class and Bisphenol-A-Co-Epichlorohydrine. Three different grades of amines were employed as curing agents, the results show that tetraethylenepentamin has the best curing properties due to the presence of more reactive sites for nitrogen and hydrogen which creates better cross-linking tendencies. The following conclusion can be drawn from the work;

- (i) The energy absorption mechanisms for composites have been identified to depend on thickness of fibre, hardness, delamination and plastic deformation.
- (ii) The mechanical properties were found to heavily depend on the grade of fibre (fibre weight), the ratio of amine to epoxy weight, the ratio of epoxy to fibre weight, the thickness of fibre and the type of curing agent applied.

The various values of tensile strength, toughness, impact strength obtained are in agreement with the works of other researchers [9], [10], [11], [12].

The results of the various tests show the possible areas of application of the developed PMC to include protective wears such as police vests, helmets for sports, safety helmets for factory use, mine shoes and knee covers for the military.

### 5.0 RECOMMENDATIONS

This project has untapped potential and may eventually be a major factor in the use of polymeric materials for military waers in the future. The following recommendations are hereby made;

- (i) The use of various additives such as agricultural waste fibres (functionalized dendetric hyperbranched polymers), high density polypropylene, fly ash and polysulfide are to be explored.
- (ii) Future work should also include the establishment of optimal processing parameters for the production of modified resins using NBR.

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