International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-6, August, 2019

Mechanical Properties of Fabricated CFRP with Filler

Pankaj Charan Jena

***Abstract:** In this paper fabrication of carbon fiber-based hybrid composite was carried using graphene and industrial waste (Fly-ash) as filler material in different percentages. Fly-ash was chosen as it is a major industrial waste. The graphene possesses various functional properties that made good interfaces with epoxy and carbon fibers. Fillers (graphene and fly ash) are considered to improve the reinforced strength, surfacing characteristics, toughness of the reinforced composite plate like structure. Properties like compressive strength, tensile strength, hardness and impact strength of carbon fiber reinforced polymer (CFRP) with fillers are tested. The change in the properties of CFRP composites attributable to mechanical interlocking of graphene and fly-ash with epoxy and fiber was observed.*

***Keywords:** graphene, fly ash, composite, carbon fiber, mechanical properties, matrix, filler.*

I. INTRODUCTION

The use of composites dates back to the dawn of mankind when glued layers of wood, bone, and horn were used to make bows, arrows, straw and clay reinforced wooden huts for shelter and survival[1]. Now FRP composite are immensely used in various applications like aviation industry, locomotive sector, submarine blades, sports [2]. Over the decade, composites have improved the structural performance of space crafts and military aircrafts. It is safe to say that the composites have quite an appealing future with the discovery of various filler materials like graphene which can help in increasing the strength, conductivity, heat resistance [3]. Unlike metallic alloys the components of composite material retain their individual chemical, physical, and mechanical properties. The benefits of FRP are low density, high strength and stiffness [4]. Reinforcements which are generally fibers act as backbone of composite materials. In some cases, reinforcements can be particles or flakes. The main purposes of reinforcements are to transmitting load along fiber direction and moderating the properties as per industry desired [5]. The reinforcing fibers are rod like structures used to support the composite. These rod-like structures are called filaments. These filaments are grouped into bundles named strands. These strands can be clubbed together in many different ways to achieve different properties in composite[1].

Different types of reinforcements used are:

Glass fibre: It exhibits useful properties like hardness, transparency, resistance to chemical attack, strength, flexibility [4].

Aramid fibres: Polyamide containing at least 85% directly attached to two aromatic rings is called aramids. The most commonly used aramid is Kevlar. Other aramids are Twaron, Nomax, Heracron [4]. Carbon fibres: Carbon fibers exhibit moderate strength and modulus in range 85-90 msi. They also offer excellent compression strength for structural applications up to 1000 ksi. Pitch fibres are made from petroleum or coal tar pitch. Pitch fibres extremely high modulus values and favorable coefficient of thermal expansion make them the material used in space applications[6]. Carbon fibres are more expensive than glass fibres. However, carbon fibres offer an excellent combination of strength, low weight and high modulus. The tensile strength of carbon fibre is equal to glass while its modulus is about three to four times higher than glass. Carbon fibre composites are more brittle (less strain at break) than glass or aramid. Carbon fibre can cause galvanic corrosion when used next to metals. A barrier material such as glass and resin is used to prevent this occurrence[4]. The primary function of the matrix acts as a binder which transfers stress among the reinforced fibers. It also protects the fibers from environmental damage. Resins (matrix) are classified as (i) thermoset (ii) thermoplastic [4]. Thermoplastic resins are soft when exposed to heat and it takes the shape of pattern by cooling. Thermoset resins are generally liquid which is cured using a catalyst or hardener which react with the epoxy resin to cure and set into a permanent solid. Once cured epoxy resin cannot be reversed back into its original liquid form. If it is heated then it will burn rather than melt. The most commonly used resin and the one used in this project is epoxy[4].Carbon fiber reinforced polymer (CFRP) composite has been proven as reliable materials and being used large scale. Graphene is used in present work as filler to analyze the change in hardness, impact energy and surface toughness of the CFRP composites as compared to normal CRPF composites. As Fly ash is a major industrial waste and decomposition of fly ash is difficult, so as a waste management initiative, it is used in this work as a filler material along with graphene. To improve the mechanical properties like hardness or surface toughness, impact energy of carbon fibre reinforced composite plate like structure is fabricated by adding graphene as filler. Further to reduce the cost of composite, industrial waste like fly ash is used as filler by varying the weight percentage (2.5%, 5%) with addition to graphene. Various mechanical properties are examined to analyse and compare with the carbon fibre reinforced composite plate like structure with no filler. Different materials like graphene oxide can be used as filler materials to manipulate various properties of the composite materials.

Revised Manuscript Received on October 30, 2019.
* Correspondence Author
Dr. Pankaj Charan Jena*, Ph.D in Mechanical Engineering, Jadavpur University, Kolkata, India

In this project fly ash is considered as a filler material and the changes in properties are observed. Supporting materials like silicon spray (releasing agent) is used for during fabrication. On the other hand graphene oxide is non-conducting because when graphene is doped with oxygen and the free electrons get engaged[7].

Fly ash is procured from the industries which are waste of burnt coal. Fly ash can have wide range of composition depending upon the type and grade of coal used. Fly ash is a major soil pollutant which can cause various problems if not dumped properly. Decomposition of Fly ash is a slow process and it can take thousands of years. These days' fly ash has used by the brick industries to make bricks and other building components. This project is an attempt of including Fly ash in the making of composites ultimately leading to decrease in carbon footprints by the fly ash[8].

Figure 1: Fly ash.

Silicone spray is a lubrication used in moderate machineries. It prevents sticking of materials together. In this project it is used as a release agent. It helps in releasing the cured carbon fiber from its mold[9].

Since the end of 3rd industrial revolution there have been the concerns of weight, strength and other mechanical properties of conventional structural materials like steel, aluminum. This concern gave rise to the inventions of composite materials. On the other hand, there has been a sharp rise in all kinds of pollutants, industrial waste and environmental issues. So, this is high time when there must be an effective way of incorporating industrial waste in the fabrication of structural composites.

There have been various research findings throughout the evolution of composite materials showing the enhancement of mechanical and physical properties with the use of graphene. The details of those researches have been briefed under the Research Gap. But there haven't been any researches using any industrial waste significantly in the development of structural composite materials. This is the reason why dumping of these pollutants have been a major issue over the years.

Fly ash is a major industrial waste and there have been some attempts in using the fly ash for constructive purposes. These days brick factories are using up some amounts of these fly ash for making bricks. Other than that, there haven't been any significant uses of fly ash. Srivastav and Shembekar (1998) observed the surface energy by adding fly ash filler (6.5 vol. %) to FRP composites. The fly ash acted as: firstly it enhanced the properties of composites and secondly it decreases the cost by acting as filler material [10]. Rahman et al. (1999) have explained the machinability of CFRP. They have modified the machining parameters (cutting speed, depth of cut and feed rate) for better machining of CFRP. With the help of cutting tool like uncoated tungsten carbides, ceramic and cubic boron nitride (CBN) the machining carbon epoxy composites have done. They have stated that depth of cut, feed rate and cutting speed for carbon fiber composites influence surface finish and cutting force. They have observed these tools have greater tool wear properties and better surface finish with comparison to conventional tungsten carbide and ceramic inserts[11]. Gong and Lics (2000) have investigated the role of non-ionic surfactant with 1% weight carbon nano tubes in a composite. They have concluded that the glass fiber temperature increases from 630 to 880 centigrade. The elastic modulus also increases by 33% and the thermo chemical properties also increase [12]. Gilat et al. (2002) have studied that carbon epoxy composite are obtained higher stiffness with increase in strain rate [13]. Fidelus et al. (2005) have investigated the thermo-mechanical properties of epoxy carbon nano (single and multi-wall carbon nano tubes) composites with low weight fractions of randomly oriented. As per the result they have concluded that EPON 815 epoxy and its composites have excellent damping properties than LY564 and its properties. The elastic modulus of single wall carbon nano tubes based nano composites has more than the value predicted by the Krenchal model for short fiber composites with random orientation [14]. Banakar et al. (2012) have described the mechanical properties i.e. tensile and flexural strength of epoxy resin composites reinforced with carbon fiber. They have shown that the tensile and flexural strength are higher in 900 fiber orientation the specimen sustained greater load at 900 orientations than other [15]. Hague et al. (2013) have attempted to study the fly ash applications in engineering industries. They have stated that application of fly-ash in engineering industries can have good importance [16]. Pathak et al. (2016) have demonstrated that excellent enhancement of properties by presence of graphene oxide in CFRP composite. They have observed the bending strength is increasing 66 % and elastic modulus is 70 % by adding 0.3 weight percentage graphene oxide [17]. Jesthi et al. (2018) have presented mechanical and physical properties of fabricated FRP composite. They have taken glass fiber and carbon fiber for reinforcement in hand layup technique. The result has stated that tensile and flexural strength of composite increased by 10.5% as compared to conventionally made composites. They have given the tensile strain and flexural extension are 17.5% and 38.5% higher and also toughness increases by 18% and flexural modulus is 26% higher [18].

It is observed that there have been many researches on the enhancement of composites by using graphene and various other materials as mentioned in the literature review. Also, various ways have been found to use Fly-ash which is a major pollutant as in the case of brick factories but there is no significant research in the direction of incorporating fly-ash in fabricating structural composites like carbon fibers.

II FABRICATION OF COMPOSITES

A. Materials used for fabricating CFRP are:

Graphene particles with size 5-10 µm and average thickness 3-9 nm are considered as filler for present fabrication.

Carbon fibre (bidirectional) with thickness 200 GSM is used for reinforcement.

Epoxy resin (L 12) is taken. The hardener K 10 is used as a curing agent.

Silicone spray is a releasing agent and it was applied during fabrication process. During fabrication silicon spray is applied on the Teflon sheets just before the mixture is pour on Teflon sheet and again when the fabrication is done, again the spray is applied to another Teflon sheet and it is kept on the fabricated composite.

Fly ash is a major industrial waste so it is examined in our present work as a filler material .Fly ash having particle size of 75 micron is used after a sieve analysis test.

Graphene and fly ash are taken with varying weight percentage (2.5%, 5%) to compare mechanical properties.

Fabrication procedure steps followed for fabrications are:

The woven carbon fibre mat was taken and five pieces were cut according to the required dimension (250×110 mm) weighing approximately 30 grams each. Epoxy with 10% of hardener weighing about 82.5 gms as determined by the mixture rule [19] was taken for preparation of the sample. Graphene (2.5 wt. %, 5 wt. %) and fly ash (2.5wt. %, 5 wt. %) were also added according to the required weight percentage (wt. %). During preparation first epoxy was poured in a container and then stirred thoroughly for some minutes, then filler materials are added, at last hardener is added and stirred for next 10 minutes. Teflon sheet was cut and sprayed with silicon spray on the metal plate where the mixture is to be laid.

The mixture was laid uniformly on the Teflon sheet and immediately a carbon sheet was laid on it, the metal roller was applied gently on the carbon fiber mat to pull out trapped air in between the fibres. This process was repeated till all 5 layers of carbon fibre laid down.Another Teflon sheet sprayed with silicon spray was placed on the top of the 5th layer toact as cover and then dead weights were applied uniformly for next 28-30 hours to obtain the CFRP plates of uniform thickness.

B. Compositions of CFRP plate

In this research, CFRP plates are fabricated with varying weight percentage of fillers using hand layup techniques. The compositions of five CFRP plate specimens made are depicted in table 1.

Figure 2: A sample with 0% Graphene and 5% fly ash.

Table 1: Compositions of CFRP plate

CFRP Specimens	Epoxy in gm	Hardener in gm	Graphene in gm	Flyash in gm
1	100	10	2.5	5
2	100	10	5	2.5
3	100	10	5	0
4	100	10	0	5
5	100	10	0	0

III. CHARACTERIZATION OF CFRP PLATES

In this Section, various tests for mechanical properties are conducted and the observations are tabulated and interpreted.

A. Tensile and compressive testing

Tensile and compressive strength testing using UTM

UTM is used for testing like tensile strength and compressive strength of fabricated CFRP composites [5]. The specimens used in this study are cut from the sheet of fabricated CFRP plates according to the ASTM standard. The gauge length for testing machine is 100 mm. A range of tensile and compressive loads are applied to the specimens by fixing adjustable grips (200 kN) using online UTM. The values were noted down for compressive and tensile test.

Figure 3: Specimens After tensile strength test.

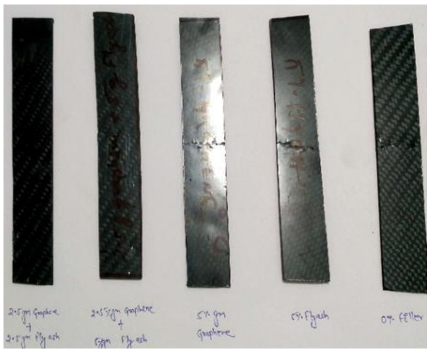

Figure4: Specimens After compressive strength test.

B.Hardness testing

Hardness is the resistance to surface indentation of the material. Hardness test of fabricated CFRP composite samples were performed using Micro Vickers Hardness Tester (Make: AFRI, Italy). For this test specimens were prepared from CFRP plates with ASTM standard.

C.Impact testing

Impact test is performed for examining the toughness of fabricated CFRP plates. Charpy tests were conducted to know the impact strength and energy absorbed of fabricated CFRP plates. The specimens (ASTM standard) dimension 50 mm × 10 mm × 5 mm were prepared and used for the test. After each test performed the absorbed energy and strength were noted.

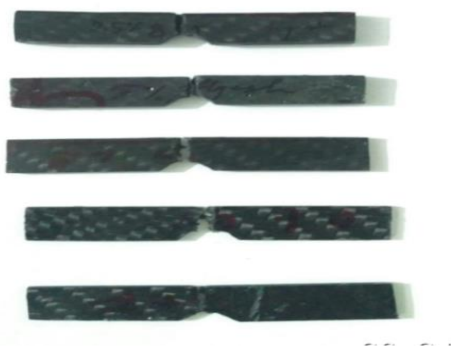

Figure 5: CFRP specimens for impact testing.

IV.RESULTS AND DISCUSSION

A. Effect of load on tensile strength

The tensile strength of CFRP plates under the various applied forces are tested and tabulated in Table 2. Stress-strain curve of different carbon fiber reinforced composites (CFRP) are shown in Figure 6 to Figure 10. It shows that as the load increases the stress and strain increases up to the yield point and then fracture occurs. In sample 1 the maximum stress value is of 0.30 KN/mm^2 in correspondence to a strain of 9.5% . In sample 2, 3, 4 and 5 the maximum stress level found to be 0.49KN/mm^2, 0.42 KN/mm^2 , 0.37KN/mm^2 and 0.29 KN/mm^2 with corresponding value of strain of 6.1%, 6.5 %, 5.1% and 4.3% respectively.

Table2: Tensile test result.

CFRP Specimens	Maximum Breaking Load (KN)	Ultimate Tensile Strength (MPa)	Extension (mm)
sample 1	15.210	304.200	3
sample 2	24.530	490.600	5
sample 3	20.790	415.800	1
sample 4	18.600	372.000	5
sample 5	14.150	283.000	2

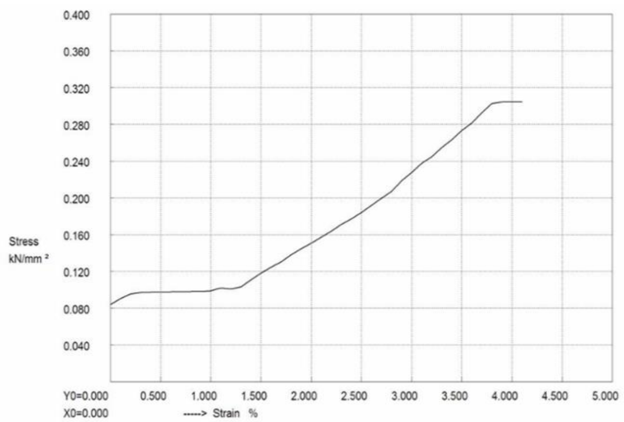

Figure 6: stress -strain curve of sample-1 .

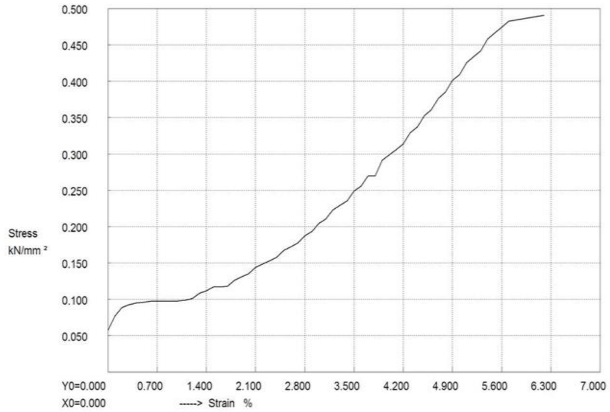

Figure 7: stress -strain curve of sample-2.

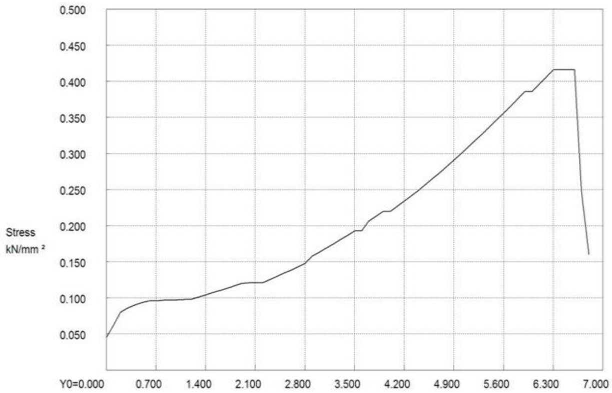

Figure 8: stress -strain curve of sample-3.

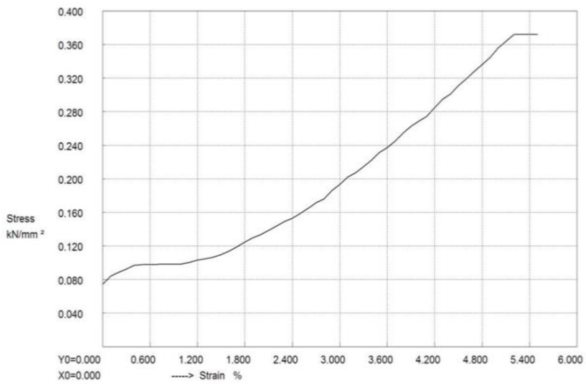

Figure 9: stress -strain curve of sample-4

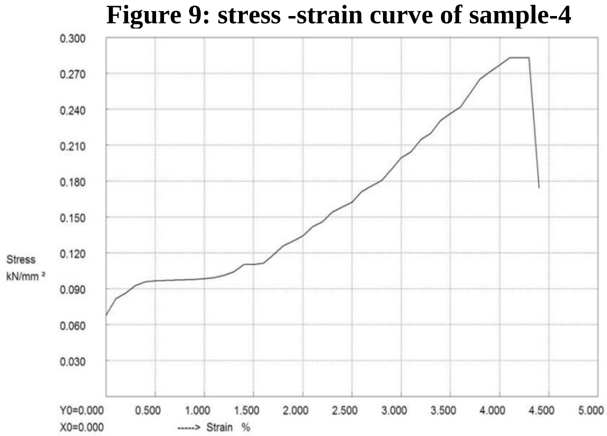

Figure 10: stress -strain curve of sample-5.

Retrieval Number E7166068519 /2019©BEIESP
DOI: 10.35940/ijeat.E7166.088619
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

In the above graphs it can be observed that stress-strain is directly proportional to load up to the yield point. After yield point the graph suddenly declines as there is no further elongation demonstrating the brittle nature of the material.
It is also found from the Table 2 that the ultimate tensile strength of CFRP sample 2 consisting equal amount of graphene and fly ash is higher than the other CFRP samples.

B. Effect of load on compressive strength

Compressive test on fabricated CFRP plates are performed and after test specimens are shown in Figure 4. The compressive strength of specimens are presented in Table 3. Stress-strain curve under compressive loading of different CFRP composition are shown in Figure 11 to Figure 15.

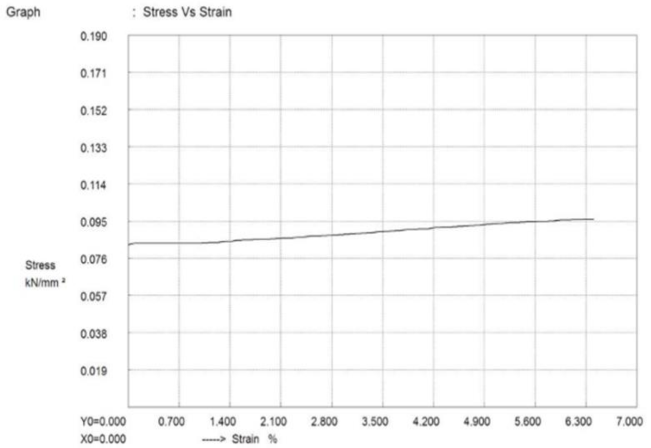

Figure 11: Stress -strain curve of sample-1 obtained from compressive test.

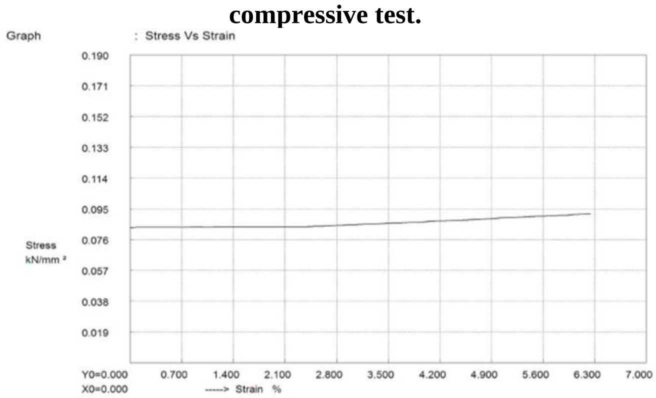

Figure 12: Stress -strain curve of sample-2 obtained from compressive test.

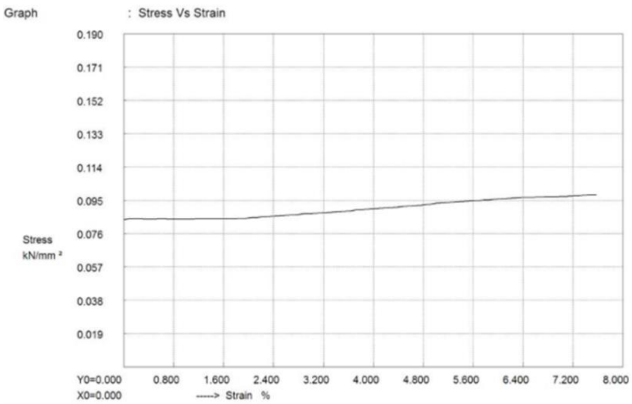

Figure 13: Stress -strain curve of sample-3 obtained from compressive test.

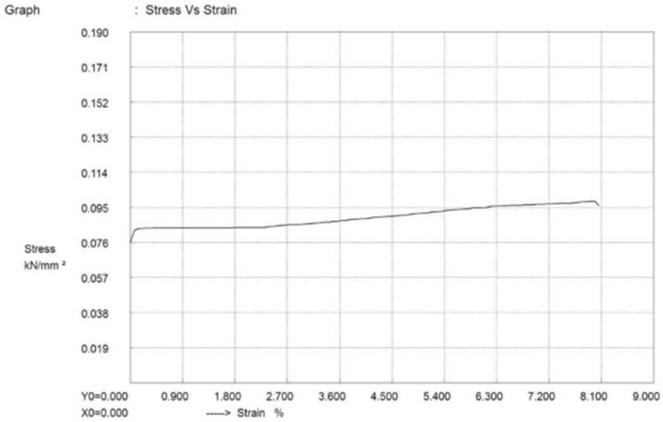

Figure 14: Stress -strain curve of sample-4 obtained from compressive test.

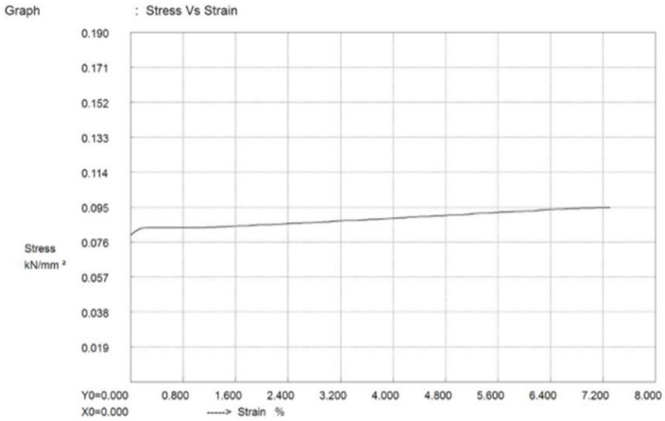

Figure 15: Stress -strain curve of sample-1 obtained from compressive test.

Table 3: Result of compressive test.

CFRP Specimens	Maximum load applied (in kN)	Compressive strength (MPa)
sample 1	4.790	95.800
sample 2	4.600	92.000
sample 3	4.900	98.000
sample 4	4.920	98.400
sample 5	4.740	94.800

It is observed from the above tabulation (Table3) that the compressive strength for CFRP sample 4, which is having 5 wt. % fly-ashes as filler material with the carbon fiber composite shows the higher compressive strength as compared to other carbon fiber composites. The maximum load applied is also the highest for CFRP sample 4 from the other carbon fiber composites.

C. Hardness testing

The Vickers Hardness tester machine was used to test the hardness of carbon fiber reinforced specimens. The readings were recorded, and the microstructures obtained were kept for further study. Indentations were taken in each sample, and the Vickers hardness number was calculated. The indentations are shown in Figure 16. Results are tabulated in Table 4.

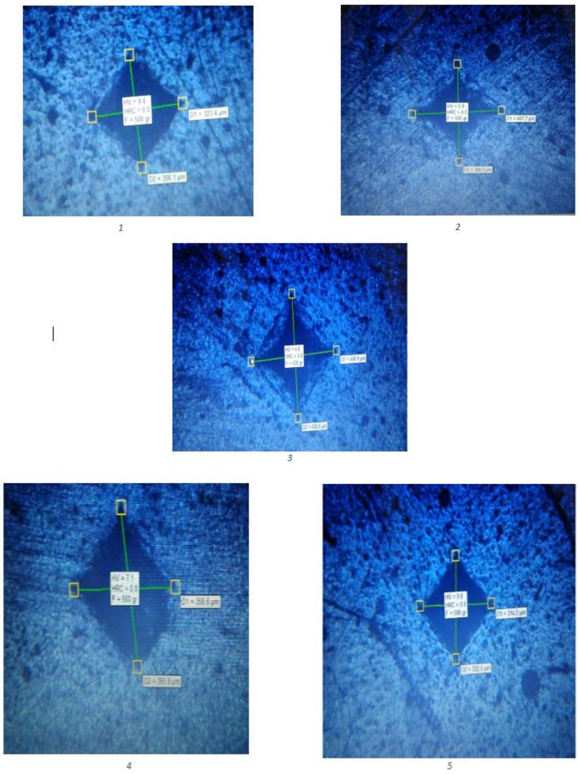

Figure 16: Hardness test result of CFRP samples Table 4: Hardness test results.

CFRP Specimens	Hardness Vickers	Force (in grams)	Diagonal (D1 in µm)	Diagonal (D2 in µm)
sample 1	9.8	500	323.4	306.1
sample 2	5.9	500	407.7	388.6
sample 3	4.8	500	450.9	430.3
sample 4	7.1	500	358.6	365.9
sample 5	9.4	500	314.2	302.5

The value of Hardness Vickers for different CFRP plates are calculated and it is found that CFRP sample 1with graphene (2.5 wt %) and fly ash (5 wt. %) as a filler elements have higher hardness value than the other CFRP samples.

D. Impact testing

The fabricated CFRP plates are taken for impact testing with ASTM standard using Charpy impact test. The readings of impact energy and strength are recorded (Table 5) for different carbon fiber composites with considering different filler percentage.

Table 5: Impact test result.

CFRP Specimens	Impact Energy (in joules)	Strength (in J/cm^2)
sample 1	2.7	6.8
sample 2	2.7	6.8
sample 3	2.9	7.3
sample 4	2.5	6.3
sample 5	3.1	7.8

From the above testing results of five different types of CFRP sample, sample 5, which is a carbon fiber-epoxy composite with graphene (2.5 wt. %) and fly ash (5 wt. %) as a filler has the highest impact absorbing energy.

V. CONCLUSIONS

The carbon fiber reinforced composites was fabricated by hand layup method with filler materials of graphene and flay ash. Experimental calculation of mechanical properties like Vickers hardness, tensile strength, compressive strength and impact energy of composites as per ASTM standard was successfully completed. It is observed that the composite having graphene of 2.5wt. % and fly ash of 5wt % as filler possess higher hardness value as compared to CFRP having only graphene and only fly ash as fillers. The ultimate tensile strength of CFRP having graphene (5 wt. %) shows the higher value compared to other fabricated CFRPs. The compressive strength is higher in CFRP having graphene as a filler material (5 wt. %) than other CFRPs.The impact energy for CFRP having grapheme (2.5 wt. %) and fly ash (5 wt. %) is highest among all fabricated CFRPs.

ACKNOWLEDGMENT

The authors do hereby acknowledge the Department of Production Engineering, Veer Surendra Sai University of Technology, Burla for providing the infrastructure facilities for carrying out this research work.

REFERENCES

1. M. Cirino, K. Friedrich, and R. B. Pipes, "Evaluation of polymer composites for sliding and abrasive wear applications," Composites, Vol. 19(5), 383–392, 1988.
2. V. K. Srivastava, P. S. Shembekar, and R. Prakash, "Fracture behaviour of fly-ash filled FRP composites," Compos. Struct., Vol. 10(4), 271–279, 1988.
3. K. Friedrich, Z. Lu, and A. M. Hager, "Recent advances in polymer composites' tribology," Wear, Vol. 190(2), 139–144, 1995.
4. M. Delamar, G. Désarmot, O. Fagebaume, R. Hitmi, J. Pinson, and J. M. Savéant, "Modification of carbon fiber surfaces by electrochemical reduction of aryl diazonium salts: Application to carbon epoxy composites," Carbon N. Y., Vol. 35(6), 801–807, 1997.
5. M. Rahman, S. Ramakrishna, J. R. S. Prakash, and D. C. G. Tan, "Machinability study of carbon fiber reinforced composite," J. Mater. Process. Technol., Vol. 89–90, 292–297, 1999.
6. R. M. Jones, "Mechanics of Composite Materials Jones 1999," Mechanics of CompositeMaterials. 2nd eddition, 1999.
7. W. Van Paepegem, J. Degrieck, and P. De Baets, "Finite element approach for modelling fatigue damage in fibre-reinforced composite materials," Compos. Part B Engineering, Vol. 32, (7), 575–588, 2001.
8.]. A. Gilat, R. K. Goldberg, and G. D. Roberts, "Experimental study of strain-rate-dependent behavior of carbon/epoxy composite," Compos. Sci. Technol., Vol. 62 (10–11), 1469–1476, 2002.
9. American composites manufacturers association, "Composites Basics: Materials," 1–21, 2007.
10. X. Liu, R. Wang, Z. Wu, and W. Liu, "The effect of triangle-shape carbon fiber on the flexural properties of the carbon fiber reinforced plastics," Mater. Lett., Vol. 73, 21–23, 2012.
11. X. Liu, R. Wang, Z. Wu, and W. Liu, "The effect of triangle-shape carbon fiber on the flexural properties of the carbon fiber reinforced plastics," Mater. Lett., Vol. 73, 21–23, 2012.
12. M. E. Haque, "Ndian Fly-Ash: Production and Consumption Scenario," Int. J. Waste Resour., Vol. 3(1), 22–25, 2013.
13. E. G. Koricho, G. Belingardi, and A. T. Beyene, "Bending fatigue behavior of twill fabric E-glass/epoxy composite," Compos. Struct., Vol. 111(1), 169–178, 2014.
14. . A. K. Pathak, M. Borah, A. Gupta, T. Yokozeki, and S. R. Dhakate, "Improved mechanical properties of carbon fiber/graphene oxide-epoxy hybrid composites," Compos. Sci. Technol.,Vol. 135, 28–38, 2016.

15. Kamyar Shirvanimoghaddam, Salah U. Hamim, Mohammad Karbalaei Akbari, Seyed Mousa Fakhrhoseini, . Minoo Naebe, "Carbon fiber reinforced metal matrix composites: Fabrication processes and properties," Compos. Part A Appl. Sci. Manuf., Vol. 92, 70–96, 2017.
16.]. B. E. Mallikarjuna, H. K. Shivanand, H. Reddy, and M. Hanif Ahamadsab, "Evaluation of Impact Properties of Fly Ash and S-Glass Reinforced Al-4046 Hybrid Metal Matrix Composites," Mater. Today Proc., Vol. 4(11), 2285–12290, 2017.
17. N. Luhmann, D. Doerr, and C. Chauve, "Comparative scaffolding and gap filling of ancient bacterial genomes applied to two ancient Yersinia pestis genomes," Microb. Genomics, Vol. 3(9), 1-11, 2017.
18. S. Liu, V. S. Chevali, Z. Xu, D. Hui, and H. Wang, "A review of extending performance of epoxy resins using carbon nanomaterials," Compos. Part B Eng., Vol. 136, 197–214, 2018.

AUTHORS PROFILE

Dr. Pankaj Charan Jena (Ph.D in Mechanical Engineering, Jadavpur University, Kolkata, India) is working as Associate Professor, Department of Production Engineering, Veer Surendra Sai University of Technology, Burla, Odisha, India. His current research interests include Composite Material Design and Modeling, control, dynamics and fault diagnosis using Artificial Intelligence.