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Research Paper

Thermal and Mechanical Properties of Hybrid Composite Strengthened by Carbon Fibers/Aramid Fibers

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ABSTRACT

This work deals with the thermal, mechanical and dynamic properties of hybrid composites reinforced with carbon fibers and aramid fibers, whose matrix is epoxy resin. In this study a series of hybrid fiber composite are prepared with carbon and aramid fibers as reinforcement. Thermal properties are obtained by thermal gravimetric analysis (TGA), Thermo-mechanical analysis (TMA) and hot plate analysis. Also mechanical properties are obtained by tensile and modal analysis tests. The experimental results are compared with the similar theoretical ones. Besides the effect of stacking sequence and hybrid ratio (adding the number of layers of carbon fibers), on the thermal and mechanical properties are investigated. The results show that by increasing the hybrid ratio although the weight of the sample is more, the thermal conductivity of the carbon fibers used is higher than that of the aramid fibers and this increase in thermal conductivity causes the heat to be transferred to the sample much faster and the temperature of the glass increases with the increase of the hybrid ratio. Due to the high stiffness of carbon fibers, adding it to the composite causes, the tensile modulus of the samples increases. By combining carbon fibers with aramid fibers, the toughness of carbon fibers can be increased and at the same time the brittle property of carbon fibers is removed due to the malleability of aramid fibers. It is concluded that aramid fiber has an effective role in improving failure strain due to its high toughness and malleability, while carbon fiber is very fragile. The lowest tensile strength occurs at the hybrid ratio of 29% with a value of 677.66 *MPa*. which is very close to the theoretical critical hybrid ratio. The results also show when the carbon fibers and aramid fibers are on the outer and the middle layers of the beam respectively, the frequency has a larger value because the aramid fibers have a very high impact resistance.

Keywords : Laminate hybrid composite; Aramid fibers; Carbon fibers; Mixture law; Thermal properties; Mechanical properties; Modal analysis.

1 INTRODUCTION

THE research conducted on hybrid composite structures shows that they are used because of the lack of defects compared to conventional composite structures. Due to its low density, high mechanical strength and resistance

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to chemical corrosion, resin-based composite structures are widely used in the aerospace industry, rail transportation, electronic industry, and pressure vessels [1-4]. Aramid is an organic fiber with an aromatic polyamide structure and consists of aromatic diacid derivatives with aromatic diamines. Commercial aramid fibers are marketed by Du Pont under the brand names Kevlar 29, Kevlar 49, and Kevlar 149. Aramid fibers have good properties such as low density, good toughness and impact resistance. These fibers also show tensile strength equivalent to GF and have disadvantages such as weak compressive properties and are sensitive to moisture and thermal environments [5-7]. Polyamide fiber with high strength and modulus is a type of organic fiber with high efficiency. This type of fiber has good strength and toughness and very good resistance to high and low temperatures and ultraviolet rays and thermal stability [8-10].Previous research showed that in the polymer reinforced with polyamide fibers (PFRP), because polyamide fibers have high strength and modulus, the surface adhesion of fibers with resin matrix increases and the interlayer shear strength of polyamide fibers with epoxy resin increases up to 62.5 *MPa*. [11-12]. Law of mixture and Halpin-Tsai equations are two well-known and simple methods to calculate the effective mechanical properties of nanocomposites reinforced by different nanoparticles [13-16]. To fix physical defects in composite structures, fibers can be combined together, which are called hybrid composite structures (HFRP). which have far better properties than reinforced single fiber composite structures. Defects of single fiber composite structures can be corrected by adding suitable fibers. For example, to fix the fragility of carbon fiber reinforced polymer (CFRP), fibers with high toughness and ductility can be used in combination with carbon fibers. High performance organic fibers such as aramid fibers, high molecular weight polyethylene fibers have high resistance and toughness, despite the mentioned advantages, they have disadvantages such as high water absorption and poor surface compatibility. Vemu Vara Prasad al etc [17],investigated reinforcement of basalt fibers and aramid fibers (Kevlar 129) in composites structures. Although aramid fibers are desirable in some properties, but they also have some negative properties such as low compressive strength and moisture absorption. Due to their inherent resistance to organic solvents, fuel, lubricants and flame exposure, they are used in helmets, aerospace, brake pads, washers, etc. Basalt is chemically inert, very resistant to corrosion, very resistant and has low thermal conductivity. In order to achieve a material with high utility, hybrid composites with carbon fiber/aramid and carbon fiber/glass layers were designed [18], whose mechanical properties were investigated using tensile and bending tests. The fracture surfaces of aramid and glass fibers compared to carbon fiber was complicated with entanglement and fracture. Although the carbon surfaces were relatively smooth, delamination was not observed in the aramid/carbon pair, unlike glass/carbon. Cheon et.al. presented the stab resistance mechanism and performance of the carbon, glass and aramid fiber reinforced polymer and hybrid composites [19]. They optimized stacking sequence of a hybrid composite in order to modify the weakness of fiber reinforced polymer. Kim et.al. [20] evaluated carbon fiber and p-aramid composite for industrial helmet using simple cross-ply for protecting human heads. They studied mechanical properties such as impact absorption, tensile strength, bending strength as well as heat resistance. Aydin et. al. [21] studied comparative dynamic analysis of carbon, aramid and glass fiber reinforced interplay hybrid composites. Based on the experimental and numerical results, the effective factors in determining the natural frequency and damping ratio are lamina numbers, orientation angles, and fabric types. Considering both carbon fiber and aramid fiber, and their respective composites, together, we do not know if the right combination of the two types of fiber might improve the brittleness of carbon fiber reinforced polymer and at the same time be suitable for vibrations and buckling under temperature gradient. Previous investigation has shown, the existence of polyimide fibers as reinforcement in polymer, causes strong surface adhesion of fibers with the resin matrix which increase the shear strength between the polyamide fibers with epoxy resin [22-23]. Currently researchers considered influence of aramid as well as carbon fibers with nano carbon particles on the mechanical properties of EPDM rubber thermal insulators which can be used in solid rocket motors [24].

The research done on the previous works, we observed that thermal and mechanical properties of hybrid composite beams reinforced with carbon fibers and aramid fibers have not been investigated so far. For this reason, in the present work, we first prepare several layered composite samples reinforced with carbon fibers and aramid fibers in the laboratory, and then after preparing the samples, we carry out a series of thermal and mechanical experiments to obtain the thermal and mechanical properties of the samples. Finally, we compare the obtained results with similar those based on the theoretical methods.

2 EXPERIMANTAL

2.1 Materials

Two-way Kevlar 49 fiber (aramid) is used in this work, which is made by Mike Composite in Milan/ Italy. Two-way carbon fiber 3k/200*gr* (with a thickness of 0.23*mm*, number of filaments 3000, tensile modulus 230*Gpa* and density

1.76g/cm^3) is used, which is manufactured by Youchang Company in South Korea. Commercial epoxy LY5052 with hardener 5052-1 manufactured by Hunstman company in Germany, was used.

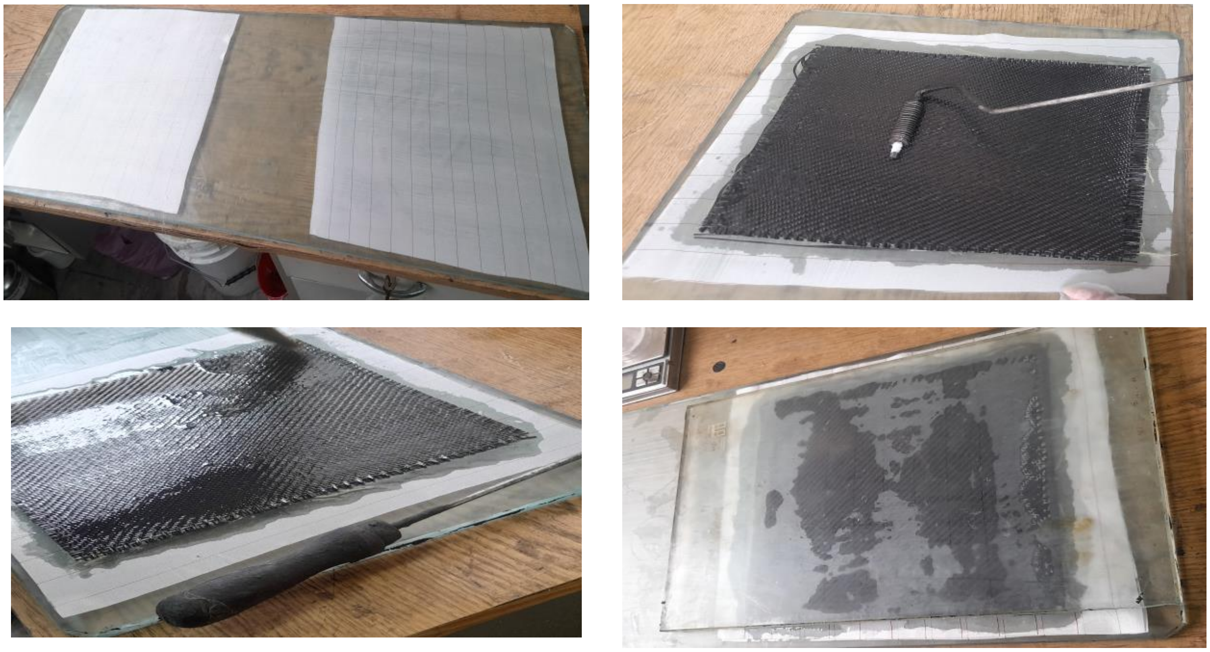
Table1
Thermal and mechanical properties of reinforcing fibers and epoxy resin.

	Carbon fiber (3K Toray T300)	Aramid fiber(Kevlar49)	Rezin epoxy(LY 5052-1)
Thermal expansion coefficient $(\alpha \times 10^{-6}(1/{}^\circ C)$	-0.5	-2	71
Conductivity thermal coefficient K$(w\ /m.k)$	14	0.31	0.15
Density $\rho(kg\ /m^3)$	1760	1440	1160
Youngs modulus $E(Gpa)$	230	124	3
Shears modulus $G(Gpa)$	96.25	47.75	2.96
Tensile strength(MPa)	3530	3620	59.98
Elongation (%)	1.5	2.8	

2.2 Hybrid composite samples are prepared by a manual method that includes the following steps

1) The mass fraction of 100:38 epoxy and hardener was used.
2) First, we cut the fibers into 25×25 dimensions with sharp scissors.
3) Put some epoxy on a flat glass surface and then stick dacron cloth (this cloth is used because the surface of the samples in mechanical and dynamic testing devices don't slide) on the glass surface and epoxy it on.
4) Use an equal amount of epoxy for each fiber layer and glue the layers together (the number of fiber layers is 4 layers) and glue another dacron fabric on top of the last layer and place another flat glass surface on them. Then we put 200 kg weights on it and put it at room temperature for 24 hours until the samples are dry and ready and reach a suitable thickness of 1.3mm.
5) Then we removed the weights and glasses and also separated the dacron fabrics from the surfaces of the samples.
6) In the last step, for each mechanical, thermal and dynamic test, it is cut to the appropriate dimensions as follows:

Now the samples are ready to perform the required tests. The pictures of the manufacturing steps and prepared CCCC sample are shown in Fig1.



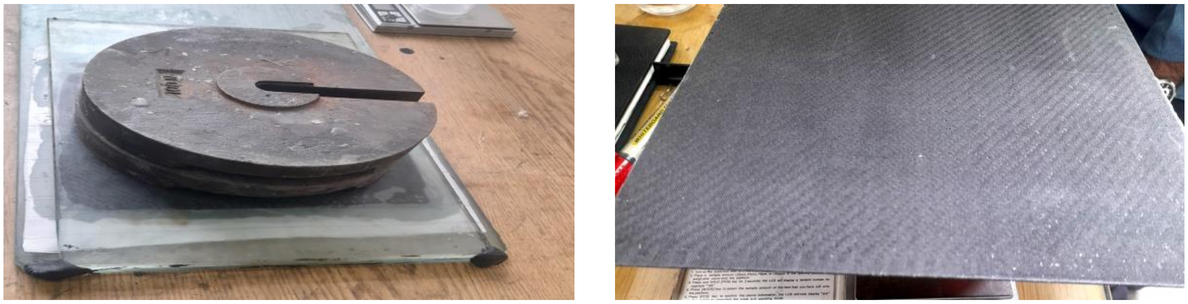


Fig.1
The pictures of the manufacturing steps and prepared samples.

The composite beam consists of four layers of fibers with an epoxy matrix, that includes carbon and aramid fibers. The mixed law is used to obtain the mechanical and thermal properties of the hybrid composite [12]:

$$P_H = P_C V_C + P_P V_P \tag{1}$$

where, P_H denotes properties of hybrid composite. P_C and P_P are properties of carbon and aramid fibers respectively. V_C and V_P are volume fractions of carbon and aramid fibers respectively. As it is known, aramid fibers have high toughness and carbon fibers have high stiffness, and by combining them and making hybrid composites reinforced with carbon and aramid fibers (HFRP) the defects of single-fiber composite are compensated [12].

In this work, hybrid ratio is defined as the volume percentage of carbon fiber in the total fiber, as follows [12]:

$$\text{hybrid ratio } = \mathrm{V_C} / \left(\mathrm{V_C} + \mathrm{V_P}\right) \tag{2}$$

In this work, the volume fraction of a layer of aramid fibers without resin is 0.0861 and the volume fraction of a layer of carbon fibers without resin is 0.1053. The stacking sequence details of the hybrid composites with four layers is shown in Table2.

Table2
Stacking sequence of hybrid composites.

Composite code		Ply number ratio (carbon/aramid)	Stacking sequence	Hybrid ratio (%)
PFRP(Carbon fiber reinforced composite)		0/4	*AAAA*	0
CFRP(Carbon fiber reinforced composite)		4/4	*CCCC*	100
H_1(Alternating structure)	*H*1-0	1/3	*ACAA*	29
	*H*1-1	2/2	*CACA*	55
	*H*1-2	3/1	*CACC*	79
H_2(P/C structure)	*H*2-1	1/3	*AAAC*	29
	*H*2-2	2/2	*AACC*	55
	*H*2-3	3/1	*ACCC*	79
H_3(P/C/P structure)	*H*3-1	2/2	*ACCA*	55
H_4(C/P/C structure)	*H*4-1	2/2	*CAAC*	55

3 RESULTS AND DISCUSSION

3.1 TGA (Thermal gravimetric analysis)

One of the most important applications of TGA (Thermal gravimetric analysis) test is to evaluate polymer compounds and measure the amount of fillers in polymers and composites. The device automatically heats the sample and then keeps it at the same temperature until the device senses a significant weight change. This technique helps to achieve maximum separation and minimum overlap between degraded components and provides more accurate analysis of polymer compounds. The onset temperature is the temperature at which the polymer begins to degrade and the highest rate of degradation occurs. The thermal stability of different hybrid ratios is evaluated by TGA analysis and the results obtained are reported in the Fig.2 as can be seen, separation and weight loss have occurred in the samples and they have started to decompose and destroy. In the hybrid ratio of 0% (4 layers of aramid fibers), the weight percentage has reached zero sooner, which can be due to the quick ignition characteristic of aramid fibers, and on the other hand, the weight of aramid fibers is less than the weight of carbon fibers used in this work. In the hybrid ratio of 29% (3 layers of aramid fibers and 1 layer of carbon fibers), adding a layer of carbon fibers instead of aramid caused the weight of the sample to be higher compared to the hybrid ratio of 0% and the weight percentage has reached zero later. In the hybrid ratio of 55% (2 layers of aramid fibers and 2 layers of carbon fibers), the weight of the sample is higher compared to the hybrid ratios of 0% and 29% and the weight percentage has reached zero later. But the hybrid ratio of 79% (3 layers of carbon fibers and 1 layer of aramid fibers) and 100% (4 layers of carbon fibers) reached zero earlier than the hybrid ratio of 55%. And it can be because of the greater number of carbon layers compared to Aramid, although the weight of the sample is greater, the thermal conductivity of the carbon fibers used is higher than the aramid fibers, and this increase in thermal conductivity causes the heat to be transferred to the sample much faster.

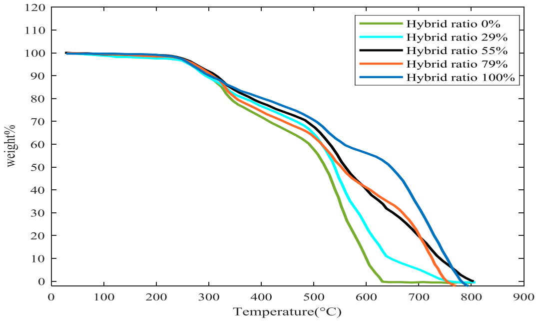
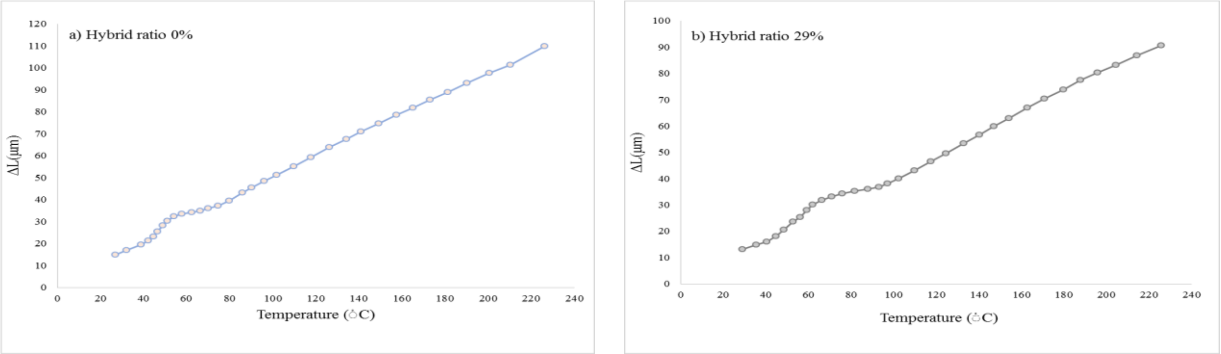


Fig.2
TGA test results for different hyprid ratios.

3.2 Thermal analysis of TMA (Thermo Mechanical Analysis)

TMA test is a very effective technique to determine the thermal expansion coefficient which is done here and its curves are shown in Fig.3 and the results are reported in Table3. In Table 3, α_1 and α_2 are the thermal expansion coefficient in the temperature range lower and higher than *Tg* (Temperature gravimetric) respectively. According to Table 3, the values obtained for *Tg* increases with increasing the hybrid ratio. The carbon fibers used in this work have a higher weight than aramid fibers, and on the other hand, the stiffness of carbon fibers is higher than aramid fibers. Also, the thermal expansion coefficient of carbon fibers is lower than aramid fibers, as a result, the glass transition temperature has increased with the increase in the hybrid ratio (increase in volume percentage of carbon fibers). α_1 and α_2 are the thermal expansion coefficient before and after the glass transition temperature, respectively. These experimental results are compared with similar theoretical ones obtained based of rule of mixture in Table 3. As observed α_2 is closer to the theoretical thermal expansion coefficient. Also, the thermal expansion coefficient α_2, decreases with the increase in the hybrid ratio, which gives a more accurate trend.



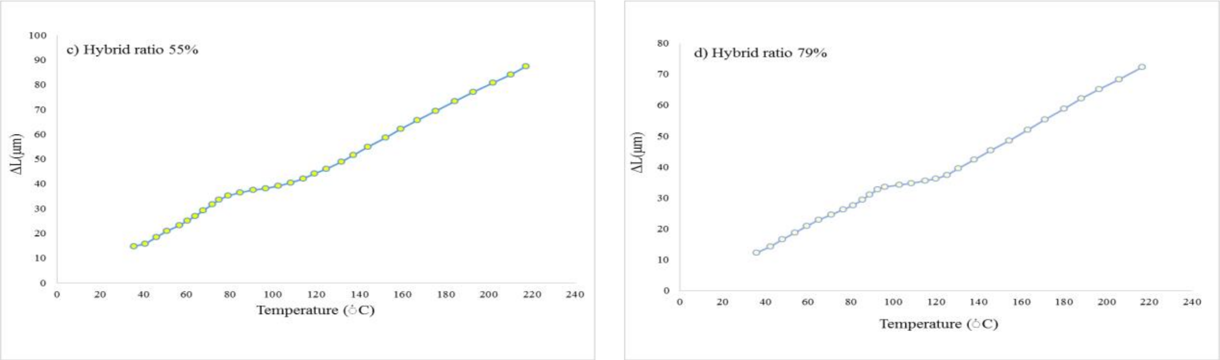


Fig.3
TMA test results for different hybrid ratios.

Table3
Thermal expansion parameters from TMA curves.

	Experimental			Theoretical
Hybrid ratio	T_g (°C)	α_1(/°C)	α_2(/°C)	$\alpha(1/℃)$
0%	66.2	39.62	57.5	45.85×10^{-6}
29%	81.8	25.0	46.25	44.61×10^{-6}
55%	90.7	22.64	48.57	43.36×10^{-6}
79%	109	32.81	41.25	42.02×10^{-6}
100%	118	26.31	32.22	40.88×10^{-6}

3.3 Tensile test

Tensile test is done by santam machine controller. For this purpose, 3 samples were used for each type of stacking sequence. Fig.4 shows a sample in the tensile testing machine.

Fig.4
Test sample in the tensile test machine.

As observed, the failure of PFRP was an explosion in which the fiber strands were scattered, which is due to the high elongation of the fibers compared to epoxy. Due to the high toughness of aramid fibers, loose strands were observed at the moment of failure. But carbon fiber has had a brittle failure due to its high stiffness, which is due to the plasticity of PFRP and the brittleness of CFRP. By combining carbon fibers and aramid fibers, the malleability and brittleness of these two fibers are improved and a composite with better properties is made. And because the carbon fibers and aramid fibers used in this work are bidirectional, their explosion is less than unidirectional fibers. The images of the samples after tensile failure are presented in Fig 5.

Fig.5
Pictures of the samples after tensile test. a) Hybrid ratio= 0%(*PFRP*), b) Hybrid ratio= 29%(*CAAA*), c)Hybrid ratio= 55%(*AACC*), d)Hybrid ratio= 79%(*CCCA*), e) Hybrid ratio= 100%(*CCCC*).

Its results are reported as follows:

The elongation at break of carbon fibers are lower than that one's of aramid fibers. Thus, when the composite is stretched along the fiber direction, aramid fibers can still bear the load after the fracture of the carbon fibers until the load increases to a certain amount. Therefore, the specimen undergoes two fracture steps before failure. Due to the high stiffness of carbon fibers, adding it to the composite and increasing the hybrid ratio increases the tensile modulus of the samples. Aramid fibers have high toughness and carbon fibers have low toughness, so the toughness can be increased by combining carbon fibers with aramid fibers. By combining aramid fibers with carbon fibers, the brittle property of carbon fibers is removed due to the malleability of aramid fibers. By combining carbon fibers with aramid fibers, the low stiffness of aramid fibers is solved due to the high stiffness of carbon fibers.

Fig.6 shows the elastic modulus for different compositions. As noticed, by increasing the hybrid ratio (increasing the number of carbon layers), the modulus of elasticity increases because the carbon fibers used have a higher modulus of elasticity than aramid fibers. Also, the stiffness of carbon fibers is much higher than aramid fibers. In Fig.7, the comparison of the experimental elastic modulus and the theoretical results based on the mixture law method is shown. As can be seen, for all the hybrid ratios, the theoretical approach gives a higher modulus compared to the experimental results, and the greatest error percentage of the mixing law is equal to 30%, which occurs in the composition ratio of 79%.

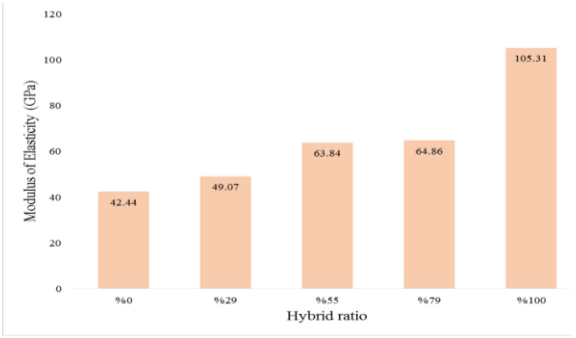


Fig.6
The elastic modulus for different hybrid ratios.

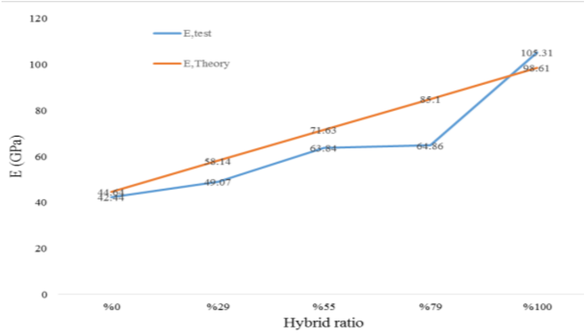


Fig.7
Comparison of the experimental elastic modulus with the theoretical one.

As mentioned above a two-step failure occurs in the composite during the tensile test. For this purpose, we can find a critical hybrid ratio, at which this two- step failure of the specimen transform to one-step failure. The critical hybrid ratio can be obtained as follows [12]:

$$V_{CC}=[1+(\frac{\sigma_P}{\sigma_C}-\frac{E_P}{E_C})^{-1}]^{-1} \tag{3}$$

where V_{CC}, , E_P, E_C, are critical hybrid ratio, tensile modulus of aramid fiber and carbon fiber respectively. σ_C, σ_P are the tensile strength of aramid fiber and carbon fiber respectively. By placing their values according to Table 1 in Eq. (3), the critical hybrid ratio is obtained, which is equal to 32%. Based on Fig. 8, which shows the experimental results related to tensile strength, it can be seen that the lowest tensile strength occurs at the hybrid ratio of 29% with a value of 677.66 *MPa*. which is very close to the critical hybrid ratio obtained based on Eq. (3). Also observed, that the highest tensile strength is 1482.52 *MPa*. for the hybrid ratio of 100%, i.e. CFRP. Fig.9 shows the variations of failure strain for different hybrid ratios. As noticed, the highest failure strain is 0.0366 for 0% hybrid ratio (PFRP). While the lowest failure strain is 0.01709 for 100% (CFRP) hybrid ratio. As the hybrid ratio increases, we can see that HFRP has a smaller failure strain than PFRP, and when the hybrid ratio reaches 100%, the failure strain is still reduced. It is concluded that aramid fiber has an effective role in improving failure strain due to its high toughness and malleability, while carbon fiber is very fragile.

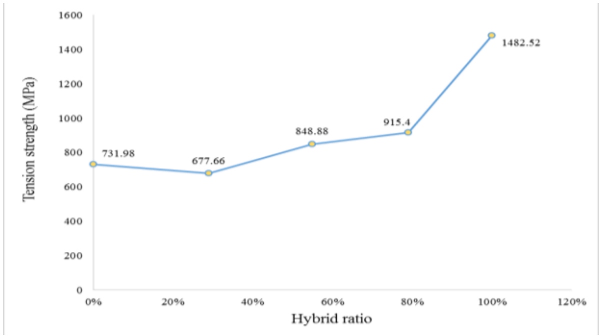


Fig.8
Tensile strength of samples for different hybrid ratios.

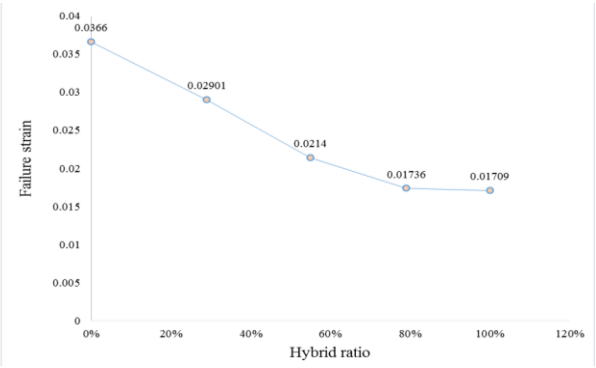


Fig.9
Failure strain for different hybrid ratios.

3.4 Hot plate test

The hot plate test is used to measure the thermal conductivity coefficient of the composite samples. Fig.10 shows the variations of thermal conductivity coefficient versus temperature for different hybrid ratios. As expected the thermal conductivity coefficient increases with the increase of the hybrid ratio. Fig.11 shows the changes in the thermal conductivity coefficient at a temperature of $25^{o}C$ and it can be seen that the thermal conductivity coefficient of the composite increases with the increase in the number of carbon fiber layers (increasing the hybrid ratio). That is because carbon fibers have very high thermal conductivity and aramid fibers have low thermal conductivity. In Table 4, the thermal conductivity coefficients obtained based on the theory method (mixed law) and the laboratory method (Hot plate) are reported. It is noticed in both methods, the thermal conductivity coefficient increases with the increase in the hybrid ratio, because carbon fibers have higher thermal conductivity coefficient than aramid fibers. The lowest value of the thermal conductivity coefficient occurs at hybrid ratio of 0% (PFRP) with a value equal to 0.3121 $W/m. ^{o}k$ and gradually increases with the increase of the hybrid ratio until it reaches the highest coefficient of thermal conductivity corresponding to 100% (CFRP) with a value of 0.7632 $W/m. ^{o}k$. The error percentage of the theoretical method compared to the experimental method can be due to the adhesion between the layers of fibers with epoxy resin, as well as the error causes by the testing device.

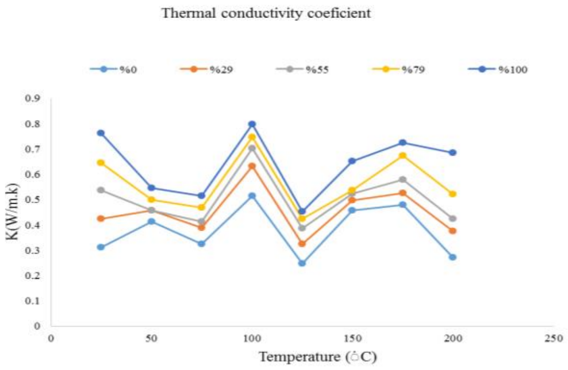


Fig.10
Variations of thermal conductivity coefficient against temperature for different hybrid ratios.

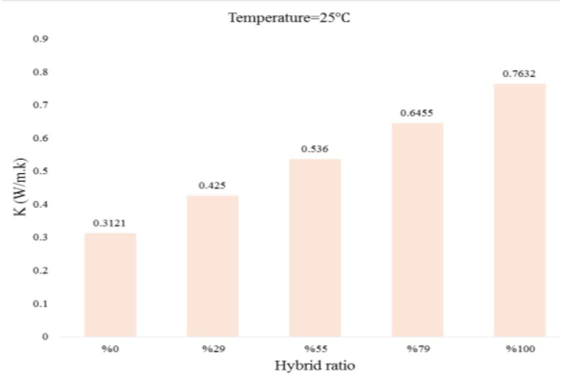


Fig.11
Thermal conductivity coefficient at $25^{o}C$.

Table 4
Thermal conductivity coefficient of the theoretical method.

	Experimental (Temperature=25^0C)	Theorical
Hybrid ratio	$K(W/m.k)$	$K(W/m.k)$
0%	0.3121	0.2048
29%	0.4250	1.649
55%	0.5360	3.093
79%	0.6455	4.51
100%	0.7632	5.96

3.5 Modal test

This test is used to extract natural frequencies. For stimulation, the impact hammer method is used, which is shown in the Fig.12 along with modal test images, test equipment, and the method of nodding and boundary conditions. This test is carried out for different hybrid ratios as well as boundary conditions.

Fig.12
Modal analysis images.

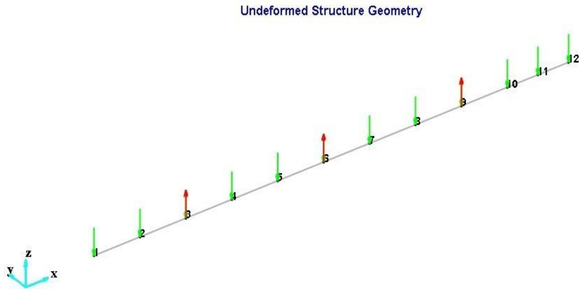


Fig.13
The geometry of the beam.

The first three modes of natural frequencies for different hybrid ratios and arrangement of composite layers are presented in Table 5. The results show the frequency increases by increasing the hybrid ratio (increasing the number of layers of carbon fibers), because the stiffness of carbon fibers is greater than the stiffness of aramid fibers. This table also shows the effect of stacking sequence and hybrid ratio on the natural frequency. As observed the highest and least frequency value is related to the hybrid ratio of 100% (single composite reinforced with carbon fibers) and 0% (single composite reinforced with aramid fibers) respectively because carbon fibers have high stiffness. Next the highest frequencies are respectively related to the hybrid ratio79%, with stacking sequence *CACC*, hybrid ratio 55% with stacking sequence *CAAC* and then *ACAC* , hybrid ratio 29% with stacking sequence *CAAA*. When the carbon fibers are in the outer layers and the aramid fibers are in the middle layers of the beam, the frequency has a larger value because the carbon fibers have a higher stiffness and the aramid fibers have a very high impact resistance. Therefore, when the aramid fibers are in the outer layers of the beam, the frequency have a smaller value because the impact resistance of aramid fibers is very significant. In Table 6, a comparison of the theoretical results with the experimental ones obtained from the modal analysis test is given. As can be seen, the error percentage of the theoretical results compared to the experimental results increases with the increase of the hybrid ratio, so that this error is more than 100% for hybrid composites with hybrid ratio more than 55%.

In Table.7 the effect of the clamped-free and clamped – clamped boundary conditions is presented for the CCCC sample. It is observed that the natural frequency for the clamped-free boundary condition has a smaller value because the clamped-clamped support has a greater stiffness.

Table 5
Effect of hybrid ratio on the natural frequencies (clamped-clamped).

Hybrid ratio(%)	Type	Stacking sequence	ω(Hz)		
			Mode1	Mode2	Mode3
0%	PFRP	AAAA	70.29	186.23	365.22
29%	HFRP	CAAA	81.44	215.11	413.75
		CAAC	95.43	252.46	486.33
55%	HFRP	ACAC	85.23	220.66	430.26
79%	HFRP	CACC	183.15	502.47	982.98
100%	CFRP	CCCC	217.35	599.50	117.57

Table 6
Comparison of natural frequencies of theoretical method with experimental results.

Hybrid ratio(%)	Type	Stacking sequence	ω(Hz)	
			Experimental	Theorical
0%	PFRP	AAAA	70.29	65.76
29%	HFRP	CAAA	81.44	75.49
55%		CAAC	95.43	87.78
	HFRP	ACAC	85.23	77.56
79%	HFRP	CACC	183.15	87.81
100%	CFRP	CCCC	217.35	88.16

Table 7
Effect of different boundary conditions on the natural frequency.

Modes	C-F	C-C
ω(Hz)	43.01	217.35

4 CONCLUSIONS

This work focused on investigating thermal and mechanical properties as well as extracting natural frequencies of epoxy/carbon fiber/aramid fiber laminated composite. The results showed:

a) In the stage of preparing the samples, it was observed that the epoxy resin was absorbed much faster in carbon fibers, while it was absorbed more slowly in aramid fibers.
b) With more carbon layers compared to aramid, although the weight of the sample is more, the thermal conductivity of the carbon fibers used is higher than that of the aramid fibers and this increase in thermal conductivity causes the heat to be transferred to the sample much faster.
c) From the TMA test results, it was concluded that the temperature of the glass increased with the increase of the hybrid ratio, and the coefficients of thermal expansion before and after the temperature of the glass were obtained.
d) The tensile test results showed that due to the high stiffness of carbon fibers, the modulus of elasticity increases with the increase in the hybrid ratio and the lowest tensile strength occurs at the hybrid ratio of 29% with a value of 677.66 *MPa*. Which is very close to the critical hybrid ratio (32%) obtained based on the theory relation.
e) The highest failure strain was at the hybrid ratio of 0% (PFRP) and decreases with the increase in the hybrid ratio, which can be due to the high toughness of aramid fibers and the low toughness of carbon fibers.
f) The modal test showed that the frequencies increased with the increase of the hybrid ratio, and the highest frequency was for the hybrid ratio of 100% (CFRP) and the lowest frequency was for the hybrid ratio of 0% (PFRP).
g) In general, it can be concluded that single fiber carbon/epoxy composites have deficiencies such as low toughness and single fiber aramid/epoxy composites have deficiencies such as low stiffness. By combining two carbon fibers, aramid and epoxy, these defects and deficiencies can be compensated and the properties can be improved and a composite with better properties can be achieved.
h) the theoretical approach based on rule of mixture gives a higher modulus compared to the experimental results, and the greatest error percentage of the mixing law is equal to 30%, which occurs in the composition ratio of 79%.

REFERENCES

[1] Sudarisman Davies I.J., Hamada H., 2007, Compressive failure of unidirectional hybrid fibre-reinforced epoxy composites containing carbon and silicon carbide fibres, *Composite Part A* **38**(3):1070-10744.

[2] Pandya K.S., Veerraju Ch., Naik N.K., 2011, Hybrid composites made of carbon and glass woven fabrics under quasi-static loading, *Materials Design* **32**(7): 4094-4009.

[3] Nordin H., Täljsten B., 2004, Testing of hybrid FRP composite beams in bending, *Composite Part B Engineering* **35**(1): 27-33.

[4] Kim S.J., Chang S.H., 2006, The relation between compressive strength of carbon/epoxy fabrics and micro-tow geometry with various bias angles, *Composite Structures* **75**(1-4): 400407.

[5] Tanner D., Dhingera A.K., Pigliacampi J.J., 1985, Aramid fiber composites for general engineering, *The Journal of The Minerals, Metals & Materials Society* **38***:* 21-25.

[6] Won M., Dharan C., 2002, Drilling of aramid and carbon fibre polymer composites, *Manufacturing Science and Engineering (Transaction ASME* **124**: 778-783.

[7] Lewin M., Preston J., 2007, Handbook of fiber science and technology, *High Technology Fibers Part B Materials and Manufacturing Processes* **6**(4): 745-748.

[8] Chang J., Niu H., Zhang M., Ge Q., Li Y., Wu D., 2015, Structures and properties of polyimide fibers containing ether units, *Journal of Applied Polymer Sciences* **132**(34): 42474.

[9] Chang J., Ge Q., Zhang M., Liu W., Cao L., Niu H., Sui G.,Wu D., 2015, Effect of pre-imidization on the structures and properties of polyimide fibers, *RSC Advances* **85**: 69555-69566.

[10] Zhang M., Niu H., Wu D., 2018, Polyimide fibers with high strength and high modulus: preparation, structures, properties, and applications, *Macromol Rapid Commun* **39**(20): 1800141.

[11] Li S., Zhuo H., Han E., Zhang D., Liu G., Tian G., Bao J., Wu D., 2020, Preparation and properties of high strength and high modulus polyimide fiber/modified cyanate resin composites*, Acta Material Compos Sinica* **37**(1): 42-49.

[12] He B., Wang B., Wang Z., Qi S., Tian G., Wu D., 2021, Mechanical properties of hybrid composites reinforced by carbon fiber and high strength and high-modulus polyimide fiber, *Polymers* **204**(9): 122830.

[13] Abdel Ghafaar M., Mazen A.A., El-Mahalla, N.A., 2006, Application of the rule of mixtures and Halpin-Tsai equations to woven fabric reinforced epoxy composites, *Journal of Engineering Science* **34**(1): 227-236.

[14] Nielsen L.E., 1974, The thermal and electrical conductivity of two phase systems, *Industrial & Engineering Chemistry Fundamentals* **13**(1): 17-20.

[15] Alfonso Lopez I., Figueroa A., Rodriguez V., Pozo L., 2016, Estimation of elastic moduli of particulate-reinforced composites using finite element and modified Halpin-Tsai models, *Brazilian Society of Mechanical Science and Engineering* **38**: 1317-1324.

[16] Halpin J.C., Kardos J.L., 1976, The halpin-tsai equations: a review, *Polymer Engineering and Science* **16**(5): 344-352

[17] Prasad V.V., Talupula S., 2018, A review on reinforcement of basalt and aramid (Kevlar 129) fibers, *Materialstoday Proceedings* **5**(2): 5993-5998.

[18] Song J.H., 2015, Pairing effect and tensile properties of laminated high-performance hybrid composites prepared using carbon/glass and carbon/aramid fibers, *Composites Part B* **79**: 61-66.

[19] Cheon J., Lee M., Kim M., 2020, Study on the stab resistance mechanism and performance of the carbon, glass and aramid fiber reinforced polymer and hybrid composites, *Composite Structures* **234**(15): 111690.

[20] Kim S., Lee J., Roh C., Eun J., Kang C., 2019, Evalulation of carbon fiber and p-aramid composite for industrial helmet using cross-ply for protecting human heads, *Mechanics of Materials* **139** (2): 103203.

[21] Aydin M., Acar V., Cakir F., Gundogdu O., Akbulut H., Akbulut H., 2022, Comparative dynamic analysis of carbon, aramid and glass fiber reinforced interply and intraply hybrid composites, *Composite Structures* **291**: 115595.

[22] Li S., Zhuo H., Han E., Zhang D., Liu G., Tian G., 2020, Preparation and properties of high strength and high modulus polyimide fiber/modified cyanate resin composites, *Acta Material Compos Sinica* **37**: 42-49.

[23] Zhuo H., Li S., Han E., Zhang D., Liu G., Tian G., 2019, Mechanical properties and failure mechanism of high strength and high modulus polyimide fiber reinforced epoxy composites, *Acta Material Compos Sinica* **36**: 2101-2109.

[24] Enew M.A., Abd Elfattah M., Fouda S.R., Hawash S.A., 2021, Effect of aramid and carbon fibers with nano carbon particles on the mechanical properties of RPDM rubber thermal insulators for solid rocket motors applications, *Polymer Testing* **103**: 107341.