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RESEARCH ARTICLE

MICROMECHANICAL ANALYSIS OF HYBRID COMPOSITES.

M. N Gururaja[1] and A. S Devaraja[2].

1. Associate Professor, Department of Mechanical Engineering, Dayanandasagar Academy of Technology & Management, Bangalore, India.
2. Professor, Department of Mechanical Engineering, Dayanandasagar Academy of Technology & Management, Bangalore, India.

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Abstract

The prediction of elastic modulus of the Kevlar/Glass hybrid composites had been investigated through Rule of hybrid mixtures (RoHM) equation. Hybrid composition were studied with different fiber percentage and the relative glass fiber contents were varied up to 100 %. The experimental and predicted values were evaluated and found excellent agreement with each other.

Introduction:-

A hybrid composite material is [1] simply a hybridization of composite materials. For example, composites reinforced with two or more types of fibers or a laminar composite material consisting of fiber-reinforced metals and thin foil metals. In some cases relating to functional materials, the term "hybrid materials" may be preferable. They are commonly used in weight sensitive structures due to their high stiffness-to-weight ratios. They are especially significant in aircraft, aerospace and military applications [2].

Several micromechanical models for woven fabric (WF) composites have been developed [3]-[5] and incorporated into PC programs [6-7], which may be used to calculate elastic and strength properties of hybrid WF composites. Results are compared with experimental values and on the stiffness, strength properties of kevlar hybrid WF composites. Moreover, in all cases the relationship between experimental and predicted values were determined & obtained. The stiffness or tensile modulus of kevlar/glass hybrid composite was analytically determined using composite micromechanical models, namely rule of mixtures (ROM) and rule of hybrid mixtures (RoHM). In this study, it is emphasized to determine the effect of hybridization by varying fiber loading on the mechanical property of the hybrid kevlar/glass fibers composites.

Governing Equations:-

Rule of Mixtures (ROM):-

There are two ways to determine the mechanical properties of hybrid composite materials, which are either using the weight fraction or using the volume fraction value of the composite reinforcement and matrix. ROM and RoHM were derived based on the volume fraction of the composite constituents. However, in practice, weight fraction was more favorable to be applied in industry due to many composite processing equipments normally uses gravimetric

Corresponding Author :- M. N Gururaja.
Address:- Associate Professor, Department of Mechanical Engineering, Dayanandasagar Academy of Technology & Management, Bangalore, India.

feeding system which has proved to be more efficient than the volumetric ones in this case[8]. Nevertheless, the relationship between the volumetric fraction and weight fraction of the reinforcement and matrix (for a single composite system) can be determined.

The assumptions made in using the ROM are as follows [9]:-
1. Fibers are uniformly distributed throughout the matrix.
2. Perfect bonding between fibers and matrix.
3. Matrix is free of voids.
4. Applied loads are either parallel or normal to the fiber direction.
5. Lamina is initially in a stress-free state (no residual stresses).
6. Fiber and matrix behave as linearly elastic materials

Rule of Hybrid Mixtures (RoHM):-
Assuming that hybrid composite system consisting of two single systems and no interaction between them, by applying the iso-strain condition to the two single systems, i.e $\sum_c = \sum_{c1} = \sum_{c2}$ (1)
where $\sum_c$, $\sum_{c1}$, and $\sum_{c2}$ are the strains of the hybrid composite, the first system, and the second system, respectively [10-12]. Force equilibrium requires that

$E_c\sum_c = E_{c1}\sum_{c1}V_{c1} + E_{c2}\sum_{c2}V_{c2}$ (2)
Then, the modulus of the hybrid composite can be evaluated from the RoHM equation by neglecting the interaction between two systems as follows:

While calculating relative hybrid volume fraction of the first and the second system, will be calculated separately.
It should be considered that the expressions listed below are valid for the assumed system
$Vc1 + Vc2 = 1$ (3)
$Vc1 = Vf1 / Vt$ (4)
$Vc2 = Vf2 / Vt$ (5)
$Vt = Vf1 + Vf2$ (6)

where Vt, is the total reinforcement volume fraction. In addition Vf1 + Vf2 should be used as reinforcement volume fraction for calculation of the elastic modulus (Ec1 and Ec2) of both of the single composites. A positive or negative hybrid effect is defined as a positive or negative deviation of the elastic modulus of the hybrid composites from the RoHM equation, which has been indicated in the presented results.

Specimen Fabrication:-
Kevlar / glass bi woven hybrid cloth materials of thickness 3 mm were used. Strength of the fibers glass & kevlar were 1400 Mpa & 2600 Mpa respectively. Whereas epoxy resin LY556 and hardener HY951 was used.

Hybrid composite laminate were fabricated at room temperature by hand layup technique. During this process bi-woven cloth of Kevlar / glass was placed one over the other by using epoxy resin, the process was continued till it reaches to required thickness i.e 10 mm, 85:15 volume fraction (fiber to epoxy resin) was maintained. Curing was carried by vaccum bagging technique at room temperature.

Experimental Methodology:-
Tensile test was conducted on kevlar/glass hybrid composite using universal testing machine. The relative effects of various properties of the hybrid composites has been discussed and tabulated.

Table 1:- Tensile test (Kevlar/Glass)

Type of specimen	Peak load (KN)	Peak stress (MPa)	Tensile Modulus (GPa)	Avg Tensile modulus (GPa)	Specific Strength (MPa/kg/m^3)	Avg Specific Strength (MPa/kg/m^3)	Specific modulus (MPa/kg/m^3)
Kevlar/Glass	29.54	409.93	29.21	**30.46**	0.29	0.286	21.08
	30.51	406.46	34.89		0.29		25.17
	29.50	393.86	27.29		0.28		19.69

Table 1 depicts the tensile properties for Kevlar/Glass hybrid composite. It is evident that the increasing of Kevlar fibers in the direction of load path increases the tensile strength. It is estimated that approximately there is an increase of 78% for specific strength. Also, it is interesting to note that which offers a superior specific strength and modulus than conventional composite system. In addition, the values of specific strength and modulus were comparable to plain Glass fiber system. This highlights the potential of hybridization effect suggesting that certain key specific mechanical properties can exceed those of more traditional thermo-plastic composites. Light weight structure is one of the keys to improve the fuel efficiency and reduce the environmental burden of several vehicles. While fiber Glass composites have been increasingly used to replace steel in an automotive industry

Micromechanical model to predict the stiffness of hybrid kevlar/glass reinforced epoxy composites:-

The overall stiffness for the hybrid Kevlar/glass fiber reinforced epoxy polymer composites calculated using the ROM & ROHM. In the simulated scenario, the fiber contents of pure kevlar/epoxy composites were gradually reduced and subsequently the glass fiber contents were also increased accordingly to maintain a constant total fiber loading content for the hybrid composites. For the single kevlar/epoxy (Ec_1) and glass fiber/epoxy (Ec_2) fiber/matrix system, predicted stiffness performance trends obtained using ROM and ROHM equations.

Table 2:- Predicted overall stiffness result for Hybrid kevlar/glass fiber using ROM & RoHM equations

Epoxy volume fraction	**Kevlar volume fraction**	**Glass fiber volume Fraction**	**Total fiber loading**	**Relative hybrid Kevlar content**	**Relative hybrid Glass content**	**Kevlar /epoxy modulus**	**Glass/ epoxy modulus**	**Hybrid Kevlar/glass/epoxy modulus**
V_m (Vol %)	V_{f1} (Vol %)	V_{f2} (Vol %)	V_f (Vol %)	$V c_1$	$V c_1$	$E c_1$	$E c_1$	E_{hc}
At Vf=0.3								
0.7	0.30	0.00	0.3	1.000	0.000	10.128	-------	10.128
0.7	0.27	0.03	0.3	0.900	0.100	9.484	4.217	8.957
0.7	0.25	0.05	0.3	0.833	0.167	9.059	4.363	8.245
0.7	0.23	0.07	0.3	0.767	0.233	8.639	4.511	7.671
0.7	0.20	0.10	0.3	0.667	0.333	8.214	4.736	6.922
0.7	0.15	0.15	0.3	0.500	0.500	7.000	5.778	6.053
0.7	0.10	0.20	0.3	0.333	0.667	5.978	5.510	5.667
0.7	0.05	0.25	0.3	0.167	0.833	4.983	5.920	5.760
0.7	0.00	0.30	0.3	0.000	1.000	----------	6.336	6.336
At Vf=0.6								
0.4	0.4	0.00	0.6	1.000	0.000	12.36	-------	18.50
0.4	0.35	0.05	0.6	0.875	0.125	11.22	5.92	17.40
0.4	0.3	0.10	0.6	0.75	0.25	10.13	6.34	16.50
0.4	0.2	0.20	0.6	0.500	0.500	8.01	7.23	11.80
0.4	0.15	0.25	0.6	0.375	0.625	6.99	7.71	7.53
0.4	0.1	0.30	0.6	0.25	0.75	5.98	8.22	7.84
0.4	0.05	0.35	0.6	0.125	0.875	4.98	8.76	8.50
0.4	0.00	0.40	0.6	0.000	1.000	-------	9.34	9.34
At Vf=0.85								
0.15	0.85	0.00	0.85	1.000	0.000	27.63	-------	**27.63**
0.15	0.80	0.05	0.85	0.941	0.059	24.77	4.36	23.57
0.15	0.70	0.15	0.85	0.823	0.111	20.60	5.12	17.86
0.15	0.65	0.20	0.85	0.765	0.235	18.9	5.51	15.75
0.15	0.50	0.35	0.85	0.588	0.412	14.75	6.80	11.47
0.15	0.40	0.45	0.85	0.471	0.529	12.36	7.71	9.91
0.15	0.20	0.65	0.85	0.235	0.765	8.03	9.92	9.47
0.15	0.10	0.75	0.85	0.118	0.822	5.9	11.13	10.50
0.15	0.00	0.85	0.85	0.000	1.000	-----	13.3	13.3

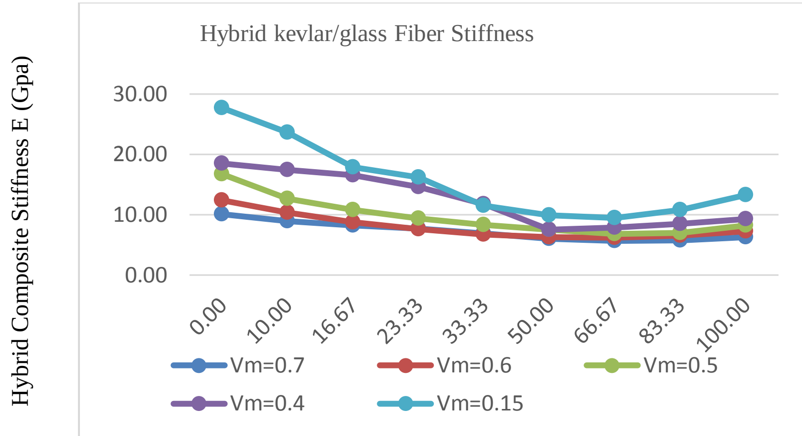

Fig.1:- Relative Glass fiber contents, VC_2 (Volume %age).

The stiffness or tensile modulus of Kevlar/glass reinforced epoxy composites was determined using the ROM and RoHM micromechanical models. The individual properties of the hybrid composites are described in Table 2. The matrix contents in volume fraction in the hybrid composition was fixed at 85% and the kevlar fiber contents was varied from 0% to 100% with respect to the glass fiber content. Later, the effect of varying the percentage fiber contents to the overall hybrid stiffness was also determined using similar micromechanical models.

As the fiber loading contents increases, the hybrid stiffness also increases as shown in Figure 1. The observed predicted trend follow the theoretical behaviour of composite materials where the mechanical stiffness increases as the fiber volume increases [13]. Higher amount of fiber increases the load bearing capacity of the overall composite materials, but as the fiber content reaches maximum (100%), the composites becomes more brittle and eventually losses its ability to retain the original shape when external load is applied to the material. It should also be noted that deviation of the predicted results obtained from the analytical method and its actual property is possible due to several factors regarding inconsistency in fiber geometry such as fiber length and diameter as well as fiber-matrix adhesion effectiveness which as assumed to be consistent in the analytical method.

Conclusion:-

In this research work, the elastic modulus of kevlar/glass hybrid composites was predicted using the rule of hybrid mixtures (RoHM) equation. This equation was employed using weight and volume fractions of the reinforcements. It was observed that the RoHM equation predicted the elastic modulus of hybrid composites a little lesser than experimental values. However, comparison between experimental and predicted modulus values indicated that the best prediction of modulus by RoHM equation was achieved when volume fraction of the constituents was employed in the equation. Moreover, in all cases the relationship between experimental and predicted values was determined & values obtained. From the obtained values good linear relationship can be expected. This also suggests that RoHM equation can be suitably applicable to the prediction of the elastic modulus of kevlar/glass and kevlar/glass fibre hybrid composites. It was concluded from the obtained results that there was a good agreement between experimental values with RoHM. The linear trend inherently present in the RoHM equation seem to be very compatible with experimental results. The overall results have provided useful insight of the hybridization effects to the stiffness of the kevlar/glass hybrid composites. This would open further opportunity towards higher application of polymer fiber based composites such as kevlar fiber in product development through the creation of hybrid material possessing technique that combined the advantages of the individual components and simultaneously mitigating their less desirable qualities.

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