Tensile Strength changeability of Multilayered Composites, fabricated through Optimized "VARTM" Technology, An experimental Approach

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Abstract-Life span estimation up to tensile fracture of different fiber reinforced composites, Kevlar Fiber Reinforced Polymer (KFRP) & Glass Fiber Reinforced Polymer (GFRP) along with the strain rate effects on dynamic properties is mainly viewed on experimental basis in this paper. Lab-scale Vacuum Assisted Resin Transfer Molding (VARTM) technique is used to fabricate flawless dog bone specimens considering ASTM standard D638-03and by using LY5052 resin and HY 5052 hardener. In this research, it is tried to maintain 65% of fiber participation in whole specimen composition matrix. Detail design description of VARTM is also discussed and optimized up to maximum scale to acquire compact, uniformly strengthen and porosity banned standard specimens. A conventional stress-strain curve is established to compare the tensile validity of above mentioned competitive composites. Crack Opening Displacement (COD) of research materials after equal intervals of time is observed; results depict the shear stability and reinforcement perfection of these materials. The crack penetration behavior is examined transversely and longitudinally in this research.

Keywords-KFRP, GFRP, VARTM, Multilayered Composites, COD

I. INTRODUCTION

A composite (or composite material) is an artificially made multiphase material in which consisting materials are different from each other physically and/or chemically. The combining components retain their specific properties in the composite but the composite overall exhibits superior properties than the individual components. The modern advancements in the technology demand unique combination of materials in order to attain the desired properties [i]. These properties have increasing demand in marine applications, transportation and aerospace industry. The aircraft industry demands anti-corrosion structural material that will have more strength, stiffness and less density. Mostly the strong material will be denser and vice versa. Therefore such desired properties could not be achieved using conventional materials. So the concept of principle of combined action was evolved according to which, a multiphase material is got by combining different materials and the resulting material has prominent exhibition of the properties of participating materials [i, ii]. This material is named as composite material or simply composite. Most common polymer based composites consists of two parts, substrate and the resin. The resins have unique shapes and can be reheated above their glass transition temperature (Tg). Upon heating, they become flexible and retain their new shapes when cooled. This is one of their major advantages that these can be repeatedly heated and shaped without affecting material properties. The most attractive property of composites, ultimate tensile strength, is enhanced by a process named reinforcement. Reinforcement increases rigidity and resists crack propagation. The pattern of the fibers decides the strengths of the reinforcement, If well attached with the matrix, thin fibers can have high strength and overall composite properties. Short and long fibers are in the form of chips are used in operations like compression molding and sheet molding etc. [iii]. Continuous reinforced materials have layered structure. A complete schematic of layered and solitary composites are described in Fig. 1. The physical properties of composite materials are usually anisotropic rather isotropic. The stiffness of composite will depend on orientation of the forces applied and design of the panel like the fiber reinforcement and matrix used orientation of the fiber axis etc. These anisotropic properties of the materials prove themselves useful in mortise and tendon joints (in natural composites) and Pi Joints in case of synthetic composites. Carbon-fiber reinforced plastic and glass-reinforced plastic together constitutes Fiber-reinforced polymers. Aramid fiber and carbon fiber are used in epoxy resin matrix in the advanced systems [iv]. Thermoplastic composite materials can be combined with specific metal powders for gaining density equivalent to that of lead (2 g/cm^3 to 11 g/cm^3). Such material is termed as "high gravity compound" (HGC) or lead replacement. These materials can replace metals such as stainless steel, brass, aluminum etc. in the applications like balancing, weighting, and radiation shielding.

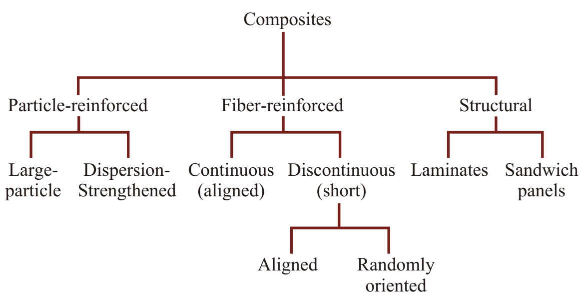

Fig. 1. A classification scheme for various types of composites

When two thin and stiff skins are attached with a lightweight and thick core, the resulting fabricated material is termed as sandwich-structured composite, providing high bending stiffness and low density. Due to shock impacts and/or repeated stresses, Composites can fail microscopically or macroscopically. Compression failure can happen at both microscopic and macroscopic level whereas tension failures can occur at a section or individual layer in the composite [v]. Different composites have different strengths and deformation levels. In this paper two types of composites materials are discussed with respect to their strength named as GFRP and Kevlar. Kevlar has important feature that it blends very well with other fibers like glass and carbon [vi]. Due to this fantastic blending ability carbon-aramid "hybrid" are used in constructions and they give the strength of carbon and impact protection of aramid [vii]. It has high strength and modulus but is weak in compression [viii]. It has best toughness and has very good resistance to damage, impact and abrasion [ix]. It can support high temperatures up to 500°C.

II. EXPERIMENTAL

Dog bone specimen of already mentioned two composites fabricated according to ASTM standards D638-03 by VARTM technology. The material test system used to examine the tensile validity of specimens is MTS 810 furnished with an advanced extensometer. The standardized dimensions along with allowable tolerances of desired specimen are mentioned in Fig. 2.

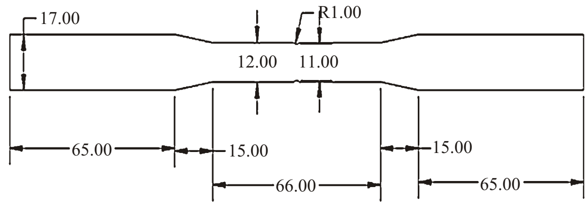

Fig. 2. Dog bone Specimen & its dimensions

A. Mold Preparation

Different metals are used as mold materials. Materials are important for better results and good experimentations. Majority of mold tool metal used lie in following categories. 1 Ni-Cr Alloy Steel 2 Mild Steel 3 Aluminum. For this research mild steel was selected as a mold material and mold contain three parts. An electric discharge wire cut and die sinking machine is used to fabricate different parts of molds.

B. Upper Mold

Upper mold play a major role for the resin to enter into the mold as it consists of inlet port and outlet ports which are opening into runners. Runners ensure smooth flow of resin from the inlet towards the channels. The diameter of inlet and outlet port is 7mm as shown in Fig. 3. Outlet opening is connected to resin trap with the help of small pipe. Inlet opening is attached with 7mm diameter nozzle which is further connected with resin chamber through 7.5mm diameter transparent gas pipe.

After machining, Viton seal of 5mm width is made around the mold. The Viton seal is placed in this cavity and permanently fixed. This seal ensures vacuum tight mold. 7mm diameter screws were used instead of clamps to achieve air tight mold.

Fig. 3. Upper Mold

C. Lower Mold

Lower Mold is the heart of the mold as it consists of three specimen cavities, which contains 5mm diameter channel on each end. Channels are in contact with the runner of the upper mold and resin flows through these channels to fill the specimen cavities as shown in Fig. 4. Specimen cavities are

7mm thick and dimensions made follow the standard D-638 exactly. Lower mold plate is removable plate so that finished product can be easily removed from the mold. Due to this reason supporting plate is placed below the lower mold.

Fig. 4. Lower Mold

D. Supporting Plate

It is actually a support to the upper two plates. Its basic function is to support the whole mold and to avoid any kind of vibrations in the mold. It allows the solid foundation of the mold and helps to get a smoother and good finished product

Fig. 5. VARTM setup

E. VARTM setup

A Typical VARTM setup consists of following parts. (1) Resin chamber and Degassing unit (2) VARTM Mold (3) Resin Trap (4) Vacuum pump. Resin chamber & degassing unit was made from Galvanized steel. It consists of two nozzles one attached to a valve and one is attached on the upper portion of the chamber. The nozzle which is attached bellow to the ball-valve is connected with the mold inlet port, from here resin flows to the mold with the help of vacuum pressure. Attaching the upper nozzle was necessary because degassing of resin was required to remove air trapped inside the resin solution [x]. The nozzle is connected with vacuum pump and degassing is done for 30 minutes to completely remove the bubbles. Resin is poured into the chamber in premixed ratio with hardener. Capacity of chamber is 400ml approx. Resin trap is one of the essential parts of the setup.

It saves the pump by preventing the excess to flow directly to vacuum pump which can cause damage the pump. So it traps the excess resin which can be reused. We designed resin trap by using a laboratory beaker. Excess resin flows through the mold outlet to the resin trap .It also helps to remove trapped bubbles inside the mold by removing the air from the mold. Clamp is used to stop the flow further to the resin trap when the mold is completely filled. Diaphragm pump was used as Vacuum pressure. This pump is used specifically or filtration purpose in research and is low pressure vacuum pump. This pump has been chosen for VARTM setup because of its advantage that it flow the resin smoothly and without any interruptions.

III. Results and Discussion

The two polymers used in this research are composed of two constituents 1. Matrix Phase 2. Resin. The detail mechanical properties of two polymers are listed in Table I. The resin used in this research was epoxy resin. It was Huntsman LY-5052 Which can be cured at room temperature. Accordingly Huntsman hardener was used (HY-5052) .Properties of Epoxy resin are listed in Table II. To optimize the VARTM setup and to produce porosity restricted dogbone specimens Mold is first cleaned with some organic solvent to remove the rubbish of the previous experiment and wax.

TABLE I

Polymer	Specific Gravity	Tensile Modulus	Ultimate Tensile Strain
GFRP	2.1	45GPa	2.3
KFRP	1.4	76GPa	1.8

TABLE II

Resin Type	Aspect	Color (Gardner, ISO 4630)	Viscosity at 25º C cps	Density at 25º C g/cm3	Flash point
LY-5052	Clear Liquid	≤2	1000-1500	1.17	≥140

Acetone was used for cleanliness; other material can be used depending upon the availability and research objective. Mold was than triple coated with mold release wax. This arrangement was allowed to sit for 10 minutes, before applying another coat [viii]. Epoxy Resin LY 5052 was mixed with hardener HY 5052.After mixing the mixture was mechanically stirred for about 15 minutes to ensure proper mixing. While mixing care was taken that stirrer the mixture slowly so that no air bubble created in it. Degassing was done with the help of a degassing chamber designed locally. Degassing chamber is connected to vacuum pump. Degassing for all type of resin was done for 15 minutes. After fabricating a flawless dog bone specimen is mounted on MTS 810 system.

The dog bone specimens of two materials, kevlar and GFRP, selected for stress strain curve are according ASTM standard code. As we are only interested in the gauge length of specimens so the area away from two necks of specimens is used for clamping. The upper calves of MTS-810 has a load cell which gives the load feedback history to data acquisition system while the deflection at the center of gauge length of specimen is observed by the extensometer attached on it. The initial application of load is selected according to specimen's geometry. Data accusation system saves each deflection along with its corresponding load. Micro excel tool is used to filter the raw data and plot the stress strain curves of the studied material. These all test are performed on room temperature. All tests are tension nature.

A deterministic route is conventional approach to explore the strength of material. In this method a single value is considered to exist which is the characteristic of the material. Practically when it is tried to find out single value strength, a researcher always faces a scattering of results. If it is supposed that the research material is perfect then the scattering of results is tagged with uncontrollable experimental variables. This method gets not much appreciates in technical sciences because according to this method, the results would be same if the same experiments are performed on test specimens of different gauge lengths. But according to already research data it is viewed that the failure stress for uniformly prepared specimen of large gauge length is less than that of the specimen having small gauge length. This difference is not totally defined by experimental random variations; however it includes imperfection random nature in yarn structure. Weibul analysis is the mostly used approach to explain the fiber strength variations as a function of fiber gauge length. In 2-parameters weibul equation the density is,

$$P(\sigma) = 1 - \exp\left[-\left(\frac{\sigma}{\sigma o}\right)^{m}\right] \qquad (1)$$

In the eq.1 the 'σ' is the tensile strength and σ_o is the reference strength related to mean value and 'm' is the weibul shape parameter. The cumulative density is estimated by using eq. 2

$$P = \frac{i}{N+1} \qquad (2)$$

Where 'i' is the recent test number and 'N' is total number of tests.

As in the recent research the gauge length of the specimen is kept constant so here weibul equations are not considered. The forces obtained from machine data acquisition system is converted into stresses by using eq. 3.

$$F = \sigma \int dA \qquad (3)$$

The result interpretation is easier to understand with the help of Fig. 6, where the load sequence is represented with respect to area dimensions.

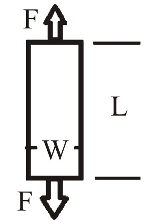

Fig. 6. Schematics of load sequence at gauge length of the specimen

As the basic dimension of the tested specimens are already known so with the help of initial design load and calculated area, which is constant for both materials specimens, one can easily determine the applied stress at the our area of interest. So as the load value is increased then its corresponding stress values are also increased causing the increment of strain rate in the specimen. On the basis of these strain rate increment behavior, it is tried to distribute stress-strain curve in different zones. As each zone of stress strain curve has its own morphology with respect to other zones even with the same zone of other material. It is also tried to relate local young's modulus with strain rates associated to that points. From conventional stress-strain curves shown in Fig.7 it is clearly viewed that at a specific stress the output strain produced is less in KFRP; however these results are plotted only in completely elastic zone [xii]. From experiments it is concluded that the area between yielding and UTS point is very minute in KFRP with respect to GFRP. However these plasticity specifications are only approachable in multilayered composite case. During solitary layer case both composite of this research show ignorable region after yielding [xiii]. As the case discussed here is multilayered and after yielding the plasticity zone explanation gets no much appreciates in these research composites, so a stress-strain behavior before yielding is enough to compare the integral parts strength.

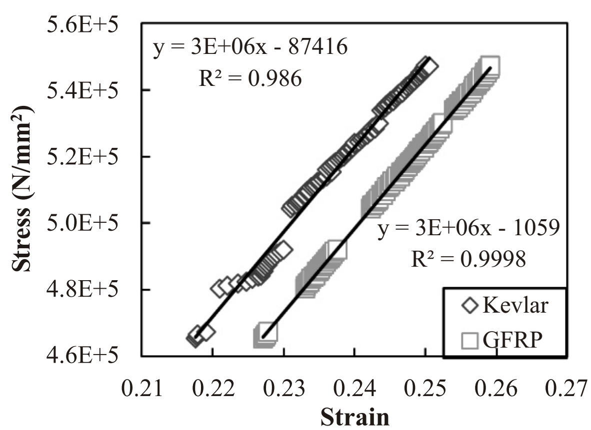

Fig. 7. Stress-Strain behavior of two polymer composites

It is explained from Fig. 6 that initially there is non-linearity between stress-strain behaviors for Kevlar but then dramatically it decreases and get smooth trend which is due to failure of fibers, however GFRP didn't show such behavior. The stress-strain trend for these composites have actually four distinct regions, three of them are graphically viewable in Fig. 7 and last is above elastic limit towards failure, not aim of this research. The first one is crimp region in which the strain increases more rapidly than that of stresses. In real cases the crimp region of each fiber has its own distinct boundary and when load applied then firstly straightens the fibers and removes their individual crimp regions. After the crimp region the elastic zone starts, now the crimp of fibers are removed and fibers are already straight so more stress is required for small increment of strain and stress strain graph shows more slope. It is the region from where we can define the Young's modulus of the material by considering the slope zone. But in this case however both of materials show a perfect elastic zone but GFRP shows ignorable crimp region, it is suggested that fibers in GFRP get already straightness while matrix is getting dried. The third region is before tensile strength, here again nonlinearity is viewed and it is possibly due to random failure of fibers but the behavior of GFRP is non-varying with respect to elastic region which shows the uniformity in strength delivery in individual fibers making the GFRP more trustable in tensile loadings. The final region is post peak regions here the required stress is very minute with respect to strain because of rapidly failure of fibers. Stress-strain curve is analyzed and used to measure the apparent Young's modulus, tensile strength, max strain and toughness for all specimens.

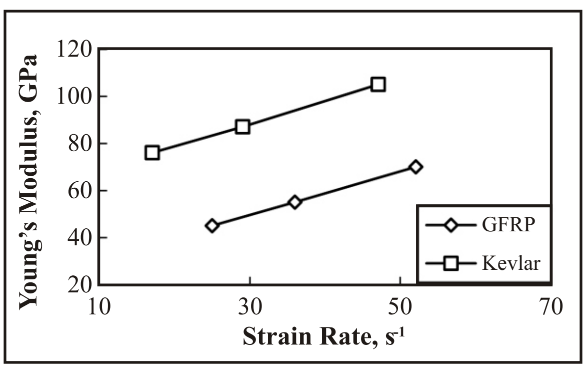

Fig. 8. Strain rate effects on Young's modulus

While discussing about elongation consistency, it is stated that in multilayered case GFRP shows more normal behavior than KFRP as shown in Fig.7. It is thought it is due to reinforcing fibers compactness variability in both composites [xiv]. It is also Expected that this behavior is due to variation in resin density distribution. Some researchers tells the reason of this phenomenon is the time based changing straightness of the fibers while the matrix is getting dried due to which inter fibers resin clotting takes place at some part of composites while uniformity is present at other part due to which minute strain variation takes place [xv].

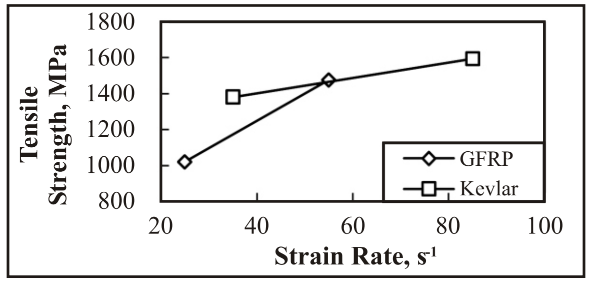

Fig. 9. Strain rate effects on Tensile Strength

In the Fig.8 the dynamic material properties of the research materials are explained in term of apparent tensile strength and Young's modulus with respect to strain rate. It is easily concluded that dynamic material properties apparently depend on the strain rate. Young's modulus behavior of Kevlar and GFRP with respect to strain rate is similar, however in the case of tensile strength there are variations between the competent materials as shown in Fig. 9. The dynamic properties behavior is studied for a fixed gage length. For Kevlar the Young's modulus increases from 76 ± 6 GPa at a strain rate of 17 s-1 to 87 ± 5 GPa and 105 ± 6 GPa at the strains rate of 29 s-1 and 47 s-1 respectively. Similarly for GFRP the Young's modulus increases from 45 ± 6 GPa at a strain rate of 25 s-1 to 55 ± 5 GPa and 70 ± 6 GPa at the strains rate of 36 s-1 and 52 s-1 respectively.

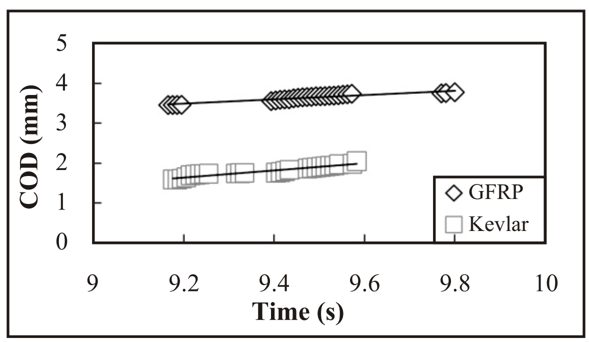

Fig.10. Time based Crack Opening Displacement curves of two composites

From Fig. 9 it is viewed that tensile strength of Kevlar increases from 1380 ± 52 MPa at the strain rate of 35s-1 to 1595 ± 40 MPa at the strain rate of 85s-1 while the behavior of GFRP didn't match with Kevlar, the tensile strength values are lower than Kevlar but abruptly increasing as the strain rate increases. Tensile strength value for GFRP raises from1020 ± 54 MPa at the strain rate of 25s-1 to 1476 ± 42 MPa at the strain rate of 55s-1.

In phase II experiments the dog bone specimens are examined with respect to time based crack opening displacement. The crack travels easily between the fibers than to cross the fibers. From Fig.10 it is depicted crack opening displacement COD in GFRP is increasing constantly which supports already mentioned hypothesis of equally distributed matrix-resin mixture in inter fiber zones IFZ [xvi]. It also justify that in GFRP the reinforcing structures remain straight without any bend to disturb the rectangular IFZ. While in KFRP the COD is less than GFRP but the behavior is increasingly in zigzag manner.

As the crack continue to propagate in IFZ in KFRP the COD behavior is linearly increasing, it deviates when a reinforcing fiber loses its straightness and obstruct the crack propagation resultantly diminish the COD with respect to previous reading supporting the fact of unequal matrix clotting in IFZ [xiii, xvii].

VI. CONCLUSION

In this research after a series of experiments, the following results are concluded;

1. VARTM is an acceptable technique to form fiber reinforced composite material if care is done to avoid air porosity beneath the fibers.
2. The stress-strain curves obtained for both tested material are totally material dependent. Effects of specimen geometry are not considered in this research.
3. The obtained young modulus values are totally localized nature against a specific zone. Overall value of young modulus for a specific material may be different than the local one.
4. The presented results are totally elastic nature. Plasticity induced during the testing is totally ignored due to complexity of mechanics and beyond from the scope of this research.
5. This study also quantifies that KFRP is two time stronger than GFRP in multilayered case in elastic zone. However, composition variation is also a known reason of inter fiber uniform clotting of resin-matrix in multilayered KFRP than GFRP.
6. Variations in strain rate affect the dynamic properties of research materials specifically on tensile strength of GFRP.
7. The crack opening prediction at specific load is more perfect in GFRP rather than KFRP due to resin coagulating in IFZ of Kevlar. The crack propagation in reinforced composites speeds up longitudinally while fades up transversely.

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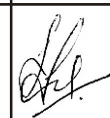
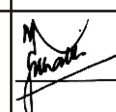
Authorship and Contribution Declaration			
	Author-s Full Name	**Contribution to Paper**	
1	Dr. Muhammad Ali Nasir (Main /Principal Author)	Proposed topic, basic study Design, methodology and manuscript writing	
2	Prof. Dr. Zaffar M. Khan (2nd Author)	statistical analysis and interpretation of results etc.	
3	Dr. Saad Nauman (3rd Author)	Data collection, Literature review & Referencing, VARTM,	
4	Mr. Saad Anas (4th Author)	Manufacturing of Composite Laminates using VARTM	
5	Prof. Dr. Asim Pasha (5th Author)	Results interpretation	
6	Prof. Dr. Shahid Khalil (5th Author)	Quality Insurer	
7	Dr. Masood Shah (5th Author)	Mechanical Testing and Data interpretation