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Preparation of transversely isotropic test specimen of glass FRP composite - an innovative approach-I

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Abstract

FRP composites have attracted attention of researchers due to ever increasing demand for lighter and stronger materials from the industry, more so from aerospace and automotive sector. Researchers, particularly in academic institutions, are suffering due to non-availability of detailed information on fabrication techniques for preparing FRP test specimens that are equivalent to an analytical model. Accurate test specimen close to analytical model reduces the compulsion of going for unrealistic assumptions that takes the analysis away from reality. An easy to follow method to design, compute and achieve correct volume fraction is presented in this work. A technique for preparing and dismantling molds with commonly available materials is presented in detail. Using simple tools and tackles coupled with a few precautions followed as described herein, prospective researchers can fabricate FRP test specimen close to their requirement.

Keywords: FRP, Volume Fraction, Test Specimen, Transversely isotropic

INTRODUCTION

FRP composites have gained enough popularity in replacing quite a few metallic components in the manufacturing sector. Researchers at various levels in general and in academic institutions in particular have taken up the development of FRP composites in a big way. Many researchers have reported about mechanical properties, static and dynamic behavior of various FRP products but there is no detailed information available on the method of preparing a test specimen close enough to analytical models. Researchers, a vast majority of them from academic institutions, are handicapped by non-availability of the literature on this subject and hence are facing myriads of problems while fabricating FRP test specimens. The problem areas are i) selection of molding tools ii) computation of volume fraction iii) sequence of molding operation. Neither any guide lines nor readymade expertise is available in the market which is culminating Into preparation of an inaccurate specimen where experimental research is unable to correspond with analytical assumptions made by the researcher.

The authors are working on micromechanical analysis of FRP composites, particularly in estimating the elastic properties of the composites of known constituents as in case of synthetic fiber reinforced plastics and vice versa. The work demands the fabrication of unidirectional continuous fiber reinforced composite samples, ensuring transversely isotropic nature. This requires placement of reinforcing fibers in a parallel and straight line orientation in addition to meeting many other specifications as per standards. Glass fibers are stronger, available in unlimited lengths, straight but highly hazardous to work with. Safer method of handling glass fiber and accurate method of Computing volume fraction are presented in this work.

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MATERIALS AND METHODS

The present work, as a first step, is aimed at preparing a unidirectional glass fiber reinforced composite specimen while addressing various practical issues that are usually encountered during fabrication. The paper sequentially touches various stages involved in a typical fabrication process aiming to guide the prospective researcher to avoid re-inventions and repetitive mistakes. Various important stages during preparation of test specimen are as following.

1. Collection and preparation of fibers
2. Computation of volume fraction
3. Preparation of mold
4. Placing and alignment of fibers in the mold
5. Sequence of recording the data
6. Resin mix preparation
7. Pouring
8. extraction of specimen and sizing

Collection and preparation of fibers

Microscopic observation reveals nodules formed at random locations all along the length of each individual fiber as shown in Fig.1. These nodules improve gripping of fibers within the resin. Required square sized (square size mat reduces wastage to naught) glass fiber woven mat is cut from the roll and stored in a clean polythene zip lock bag. Polythene bags are used both for visibility and eliminate loose fibers from flying. Individual glass fibers are too thin and brittle, hence cannot be cut with scissors. Strands of glass fibers, however, are supple and relatively easier to cut. Glass fibers are highly hazardous that warrant usage of hand gloves and nose mask as shown in Fig.2. cutting and storing operations are done in a room without any air draft.

The woven mat is kept under covers until incorporation to keep fibers clean that ensures better bonding with matrix. As the aim is to fabricate unidirectional reinforced composite specimen, fiber strands are drawn from the woven mat. Since individual fiber strands are difficult to cut with scissors, the mat is cut to the required size from which strands are drawn. The strands are grouped in bunches of 50 or 100 in number.

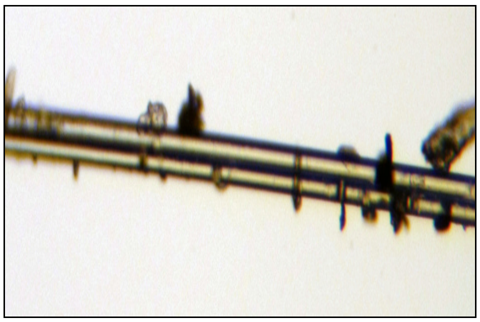

Fig 1. Microscopic view of a pair of glass fibers with nodules formed.

Fig 2. Drawing of fiber strands from the woven mat.

Computation of volume fraction

One crucial specification during preparation of test specimens is achieving the required fiber volume fraction. The procedures like *burning off* or *dissolving in a solvent* for determining the volume fraction are too cumbersome for institutional level researchers. These procedures usually determine the volume fraction in the specimen but cannot achieve a designed volume fraction. Moreover these methods are suitable only for synthetic fiber composites and cannot be extended to natural fibers. Hence, one solution is to target and compute the volume fraction prior to achieving it, which is done by determining the linear density of a representative group of fibers (in this case strands) by careful weighing and judicious averaging.

Fiber's material density is different from its bulk density. Since fibers are incorporated in their bulk form, volume fraction calculations are to be performed in situ. Glass fibers are handled in the form of strands and determining the linear density (weight per unit length) of these fiber strands accurately in their available form makes it easy to determine the true volume fraction and is a viable method for researchers in educational institutions. Fiber strands of varied numbers but of equal length are bunched together and weighed on a digital balance of 1 mg sensitivity. At least five such samples are weighed and averaged for determining the linear density of each strand. A sample calculation is shown below for achieving 10% volume fraction with glass fiber.

Target volume fraction: 10%
Specimen dimensions: 250x50x4 mm
Linear density of glass fiber strands* (calculated): 0.288 g/m
*Strands are taken as drawn from the knit mat.
Volume of the mold: 50 cc
Volume of fiber to be incorporated for 10% V_f 5 cc
Wt of 5 cc of fiber (material density: 2.54 g/cc): 5 x 2.54 = 12.7 g
Length of fiber strand to be incorporated: 12.7/0.288 = 44.097m
No. of strands to be placed in the mold: 44.097/0.25* = 176.39
*250mm = 0.25m is the length of specimen/mold

Say 176/177 strands of glass fiber are to be placed parallel to 250 mm side of the mold arranged (spread) uniformly along the width. Counting the fiber strands while drawing them from the mat prior to placing them in the mold is done to avoid possible errors.

Preparation of mold

Three methods are tried during the present work and the better one is described here. The mold base chosen is a vitrified ceramic tile. These tiles are tough, glossy smooth, nonstick and one can write with pencil and erase. Pencil lines are drawn on the tile surface as per the specimen geometry and a 2-way glue tape is pasted along these lines to form a peripheral bund. One layer of tape is pasted for every 2 mm of thickness and two layers of tape for 4 mm thickness in the present case. This is one of the most flexible methods as drawing of pencil lines on the tile surface and sticking the glue tape along the lines is done quickly and corrections can be made with equal ease. 2-way foam tape sticks and grips well to the vitrified tile surface and the bund thus formed will not allow any leakage of resin Before gelling results in accurate volume fraction. Volume of the mold is measured from the actual dimensions. 2-way glue tape also helps in sticking the fiber layers straight and aligned as illustrated in Fig. 3.

Fig 3. Fiber strands retained in parallel position and a series of molds are in line.

Other two methods use either spongy rubber mat or acrylic sheet in place of glue tape. In both the cases, pre-cutting of cavities to the required mold dimension is to be done which is cumbersome, demands a machine and hence adds to cost. Also these sheets require clamping of the mold set-up to the base and a slight leakage of resin invariably occurs that introduces errors in volume fraction. Also these molds cannot be altered in size as and when required. Fibers are to be left free in these molds which results in wrinkling and loss of alignment. Hence these methods are discarded.

The mold set-up is mounted on a heavy table as depicted in Fig. 4, to avoid accidental disturbances during pouring. The uniformity in thickness is achieved by making the mold base horizontal using a spirit level and Fig. 5 shows a few tools and tackles used including a spirit level (in the fore ground). Once casting is removed from the mold, glue tapes are peeled off immediately and the mold base is cleaned with thinner for the next operation. The time taken by the authors for preparing a mold of 5 specimens by this method is surprisingly less than 30 minutes after a few days of practice.

Fig 4. Mold set-up on a heavy bench

Fig 5. Tools and accessories used

Placing and alignment of fibers in the mold

Based on the number of strands to be accommodated per unit width of the mold, strands are hand held straight with slight pre tension and placed one by the side of the other (sometimes one over the other if volume fraction is high) and parallel to each other as shown in Fig. 6 which is a skilled and time consuming procedure. For holding the fibers, 50 to 60mm extra long fibers strands are taken. For example, to prepare a 250mm long specimen, the fiber strands must be at least 310-325mm long. The extra 60-75mm lengths will facilitate gripping and are trimmed off after the specimen is cast.

Fig 6. Aligning and securing the fiber strands in place

The progress of fiber strands placed in each unit width; say at every 10 mm is checked to keep the areal density (number of strands per unit area) of specimen uniform. Also, this is the most crucial and demanding part of the whole job to achieve uniform volume fraction in all specimens. Counting the number of strands to be placed and weighing them before placement in the mold is repeated as a precautionary measure. Pre-weighing of fibers and post-weighing of residuals is done and recorded to confirm the volume fraction. Keeping the fibers straight and parallel is not a very difficult task in case of glass fibers but due care is to be taken while handling the fibers so that none of the worker's body parts are hurt. Working in a closed room without any wind draft is a necessity to avoid fibers flying in the room which are highly hazardous.

Sequence of Recording the Data

The following data is recorded to match the actual volume fraction with the designed one.

- The square mat is weighed and the number of strands is counted.
- Dividing the weight of the mat with the number of strands gives the weight of each strand.
- Linear density of fibers is averaged on at least five sample groups and for the whole mat.
- Number of fibers strands to be incorporated (for achieving the designed. volume fraction) is counted and weighed as a cross check (as described in section 2).
- Place the fiber strands and counting after every 10 mm of progress in width of the mold is done.
- 20% extra volume of resin mix is prepared to take care of wastages.
- Weight of resin before pouring and residual's weight is recorded as a precaution.
- The prepared dry sample is weighed and compared with combined weight of resin and fibers incorporated.
- The molding is repeated if the error in volume fraction is more than 5%.

Resin mix Preparation

Important precaution while handling the resin (matrix) is to see that no air bubbles are included. Air bubbles get entrapped during mixing of accelerator and catalyst as well as during pouring of resin in the mold cavity. Turbulence while stirring or pouring is kept to minimum to avoid inclusion of air bubbles. All containers used are disposable, like paper cups and plastic syringes. The steps for preparing matrix are as following.

- Pencil marks are made on paper cups for 100, 150 and 200 ml using a graduated cup. This helps in taking required volume of resin that avoids unwarranted wastages.
- The volume of the mold is calculated and 20% extra resin is prepared.
- The cup is tilted and held close to the container while collecting resin to avoid any turbulence.

- Syringes are used for measuring accelerator and catalyst.
- Mixing of accelerator is done slowly with a thin stirrer and the mix is allowed to settle for 5-6 minutes (before adding catalyst) to expel any air bubbles.
- The mold and fiber alignment is checked once again before mixing catalyst in the resin as the time Available after the process is very short for any corrections in the mold.

Pouring

Mold is kept ready by keeping it horizontally on a heavy work table by using a spirit level. Horizontality is important to keep the thickness of the specimen uniform throughout. Pouring is done keeping the cup close to the mold by starting at the centre of the mold area and working towards outer edges. The even spread of resin in all directions is observed, which is an indication of horizontality of the mold that results in uniform thickness. Weighing of the resin before pouring and after pouring is important to ensure that a right amount of resin is consumed which matches with the theoretical amount. Measurement of resin consumed is a check for both the thickness of the specimen and volume fraction of fibers incorporated. Air bubbles (if any) entrapped in the mold are punctured with a sharp needle. Due to limited time available before gelling occurs, it is seen that no air bubbles remain in general and within the gauge length of the specimen in particular.

Extraction of specimen and sizing

Allowing three hours of setting time is found to give best results. Too early extraction results in warping and too late extraction leads to accidental breakage of specimen. As thickness and length of the specimen are fixed by the mold dimensions, specimens are cut to required width after curing. Cutting with saw resulted in cracking of the long edges as well as varying width and hence dispensed with. Laser cutting is found to be a better option. Intensity of laser beam is set at right value to avoid excess heating and generation of fire near the cutting zone. Width is computer controlled on the laser cutter and hence accurate. Finishing of specimen is done with fine emery (No.200, water proof) and all sharp corners are hand ground.

CONCLUSIONS

A lot of researched material is available on testing of FRP composite specimen and analysis of FRP composites through various software packages. However, very little information is available on how to fabricate a test specimen that is close to the assumed analytical model. This paper elaborates on various new techniques of preparing FRP test specimens. Quick and reliable mold preparation method, positioning of fibers for a transversely isotropic specimen, achieving the target volume fraction and accurate method of cutting the specimen to specified dimensions are all tried, tested and presented.

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